



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

June 21, 2018

Weather Study

METEOROLOGY

ERA18FA127

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A. ACCIDENT

Location: Crozet, Virginia
Date: April 15, 2018
Time: 2054 eastern daylight time
0054 Coordinated Universal Time (UTC) on April 16
Aircraft: Cessna C525, Registration: N525P

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 April 15, 2018, 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.

The accident site was located at approximate latitude 38.0978° N, longitude 78.7225° W, at an elevation of 1,530 feet (ft).

D. FACTUAL INFORMATION

1.0 Synoptic Situation

The synoptic or large scale migratory weather systems influencing the area were documented using standard NWS charts issued by the National Center for Environmental Prediction and the 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 2000 EDT is provided as figure 1 with the approximate location of the accident site marked within the red circle. The chart depicted a low-pressure system at 1000-hectopascals (hPa) located in southwestern North Carolina. Another low pressure system at 1003-hPa was located over central Ohio. A frontal boundary stretched from the low pressure system in central Ohio southward to the low pressure system into southwestern North Carolina. A stationary frontal boundary was oriented from west to east across the accident site with the boundary from northern West Virginia into central Virginia and eastward into the western Atlantic Ocean. A squall line boundary was indicated from central Virginia southward into central North Carolina, eastern South Carolina, and into the Atlantic Ocean.

The station models around the accident site depicted air temperatures in the upper 50's degrees Fahrenheit (°F), dew point temperatures in the mid 50's °F with temperature-dew point spreads of 2° F or less, a variable wind of 5 knots or less, overcast skies, and moderate rain.

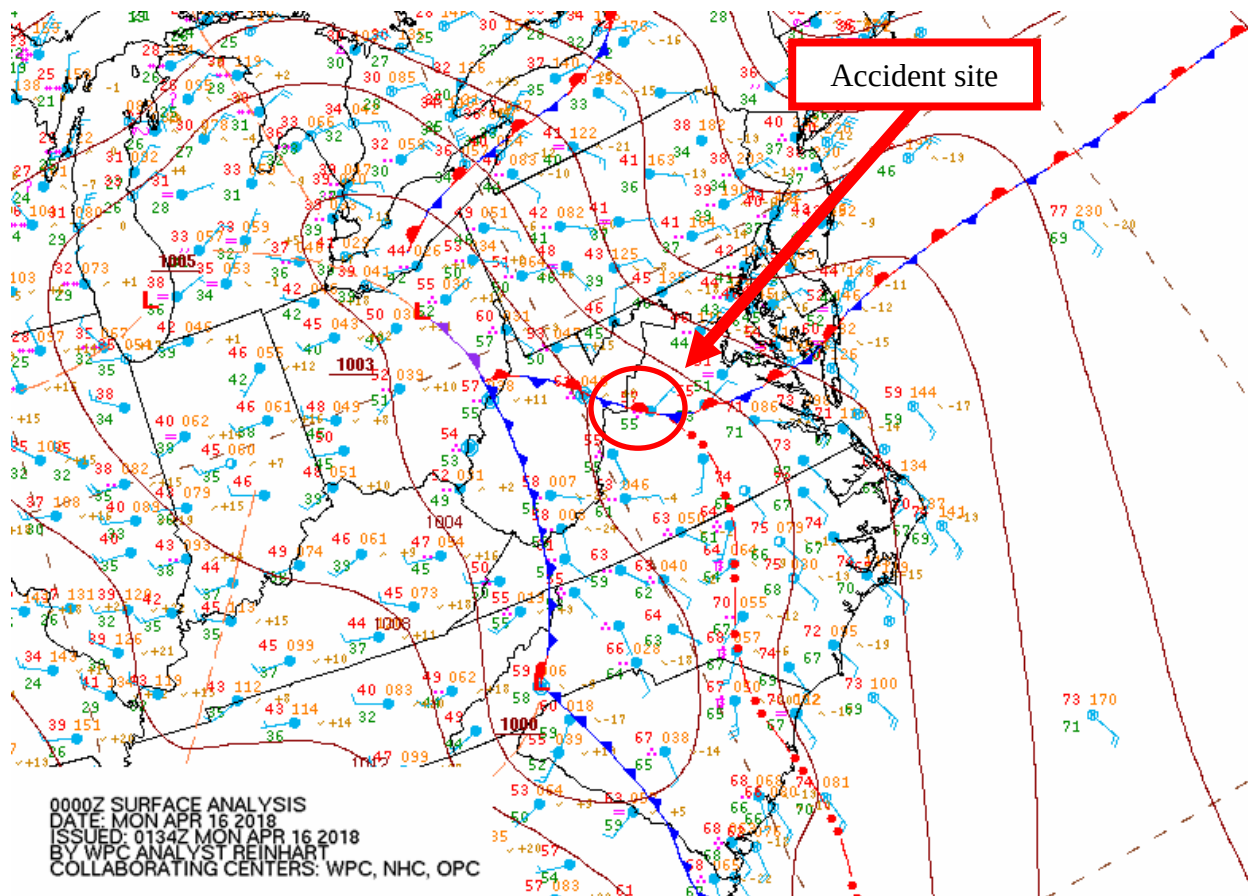


Figure 1 – NWS Surface Analysis Chart for 2000 EDT

1.2 Upper Air Charts

The NWS Storm Prediction Center (SPC) Constant Pressure Charts for 2000 EDT at 925-, 850-, 700-, 500-, and 300-hPa are presented in figures 2 through 6. There was a low- and mid-level trough² located over the accident site (figures 2, 3, and 4) at 925-, 850-, and 700-hPa. Troughs can act as lifting mechanisms to help produce clouds and precipitation if sufficient moisture is present. The troughs along the east coast were also negatively tilted.³ There was an east to southeast wind at 25 knots at 925-hPa that became a southerly 65 knots wind by 700-hPa (figure 4). By 300-hPa, the wind was from the south at 90 knots (figure 6).

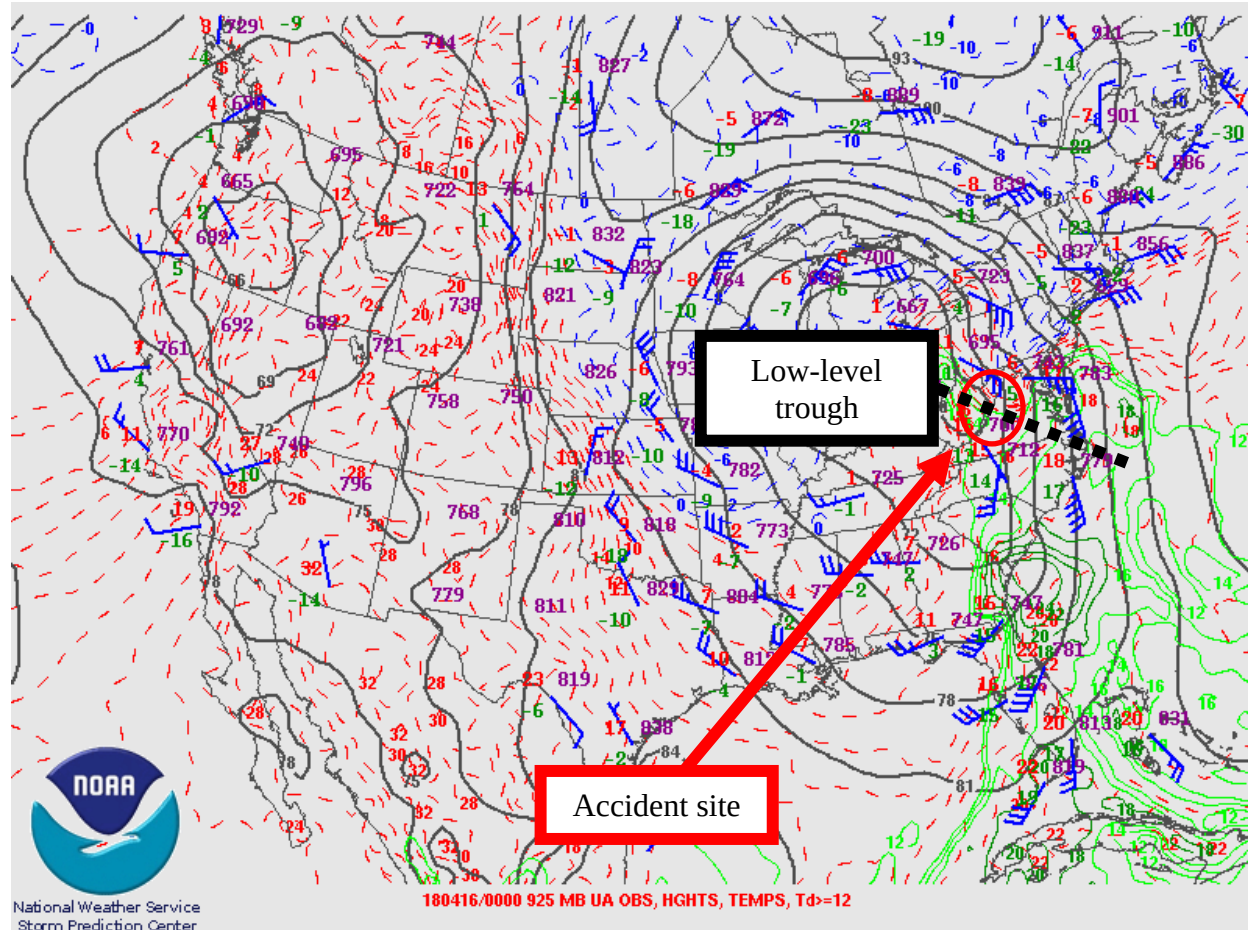


Figure 2 – 925-hPa Constant Pressure Chart for 2000 EDT

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

³ <https://www.weather.gov/jetstream/basic>

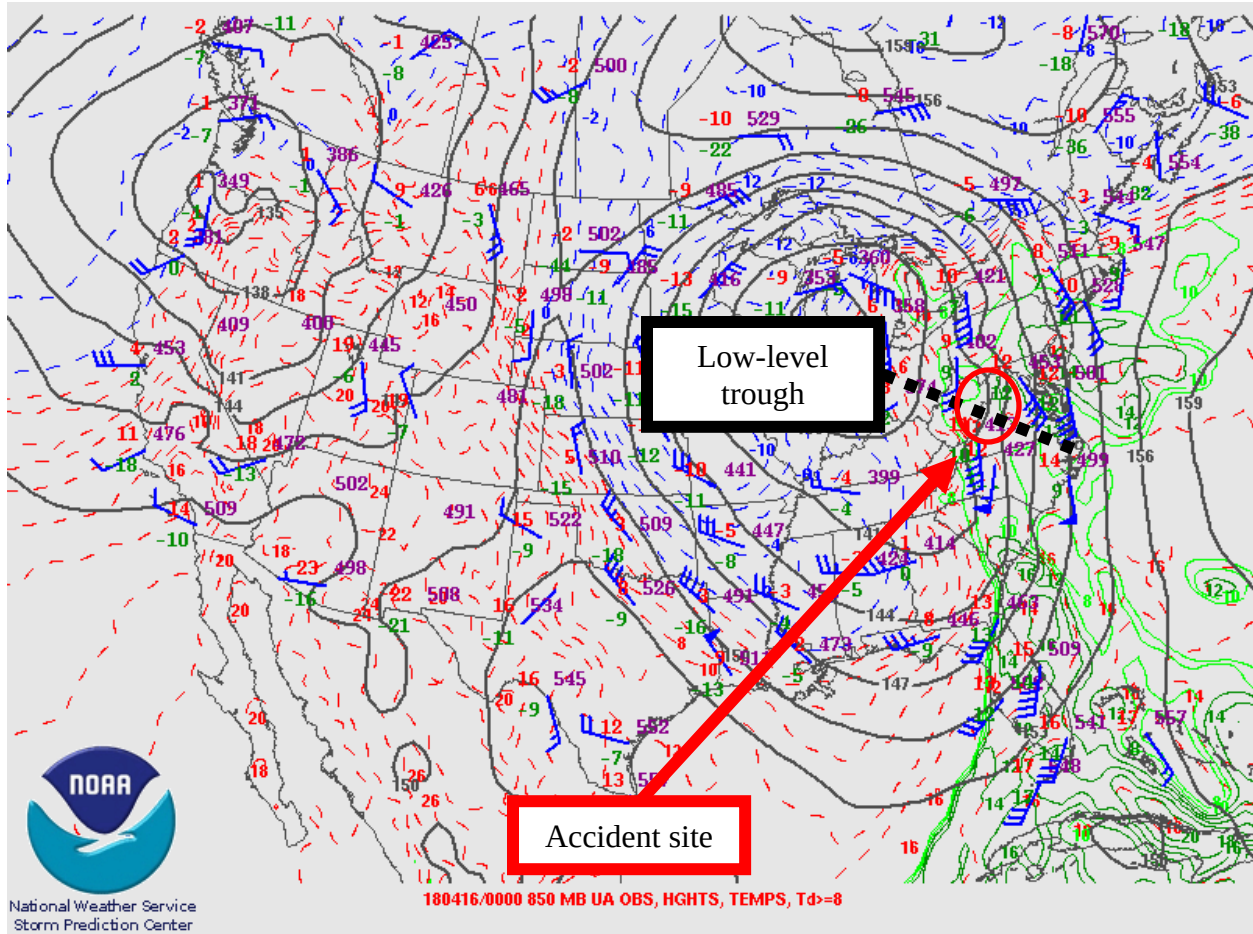


Figure 3 – 850-hPa Constant Pressure Chart for 2000 EDT

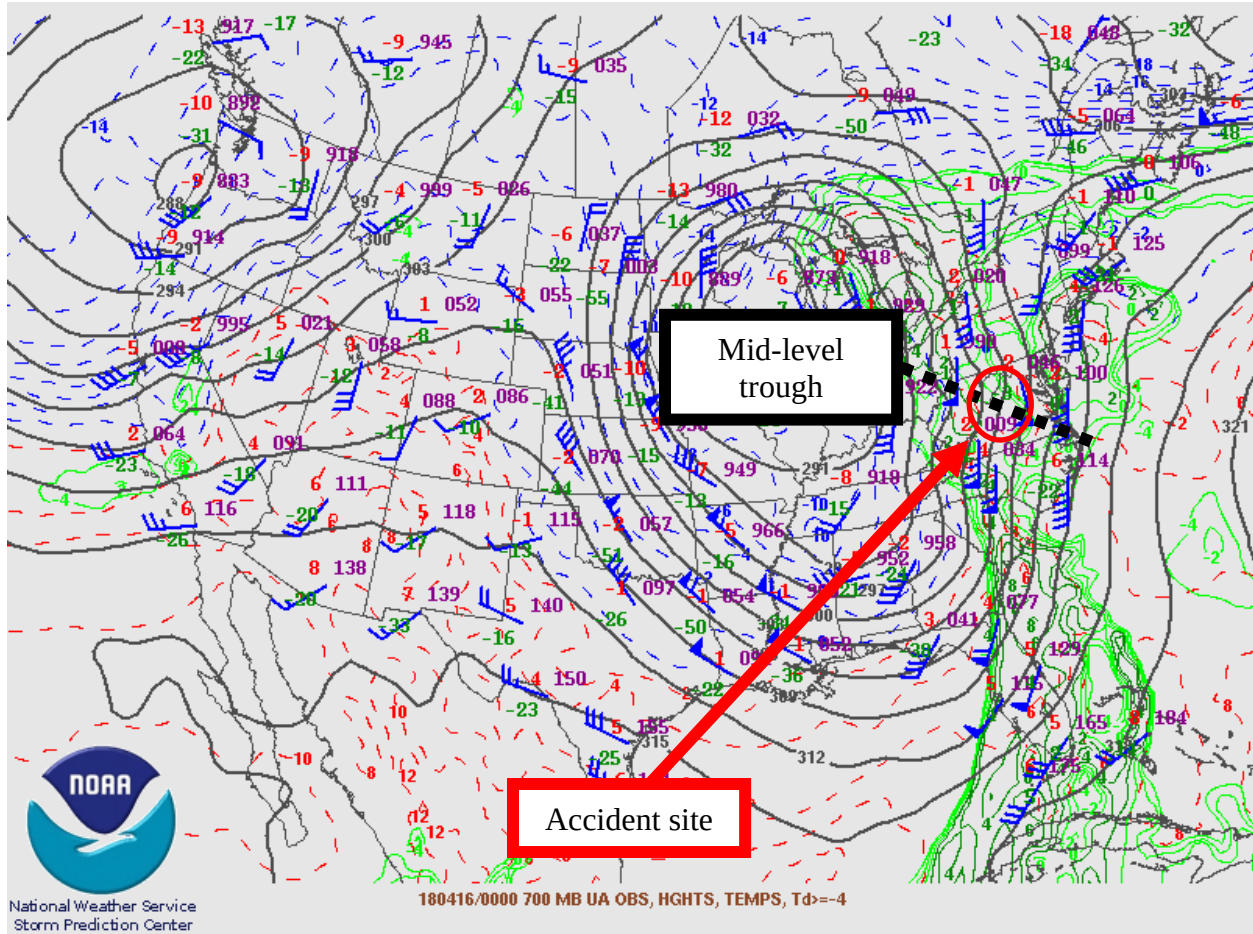


Figure 4 – 700-hPa Constant Pressure Chart for 2000 EDT

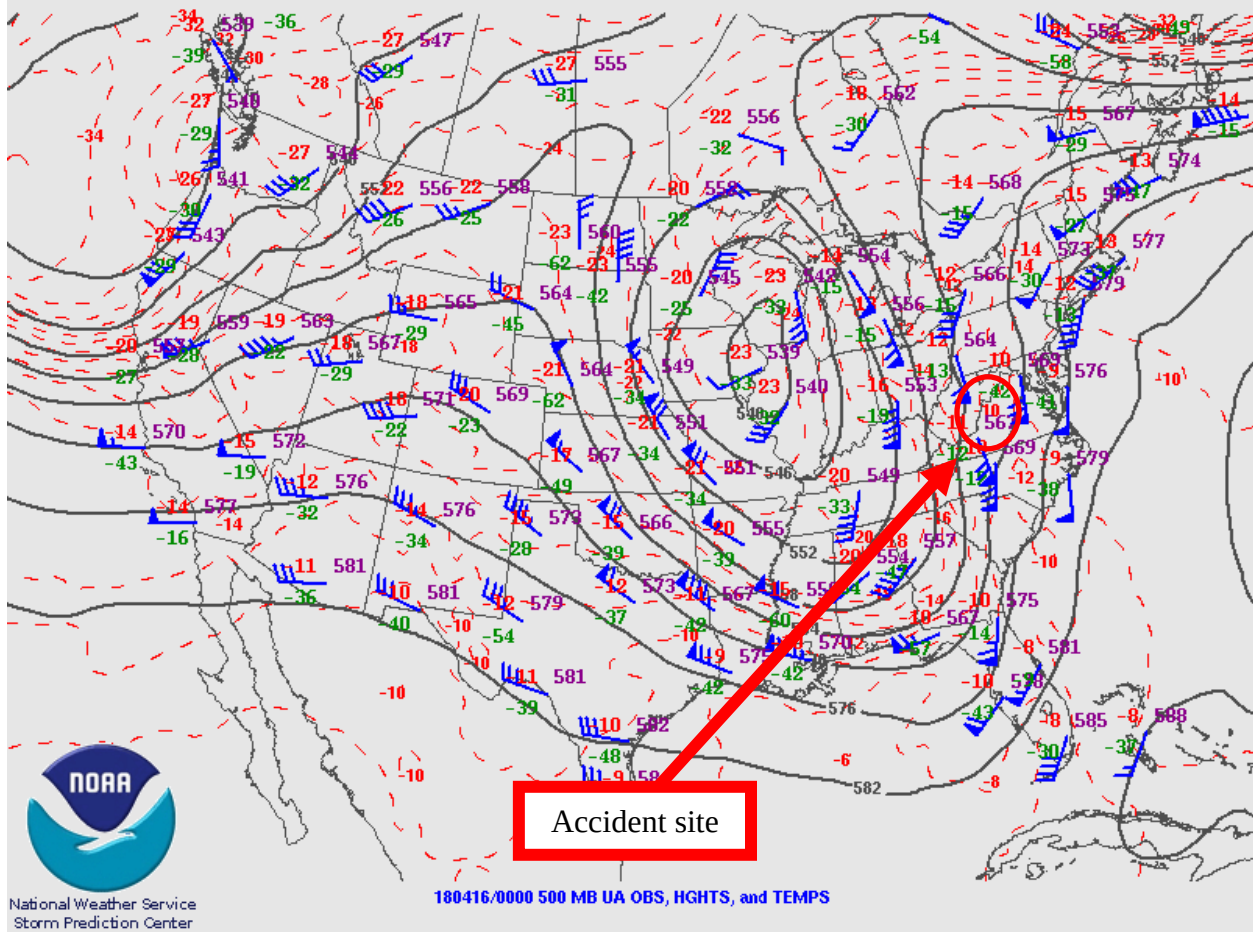


Figure 5 – 500-hPa Constant Pressure Chart for 2000 EDT

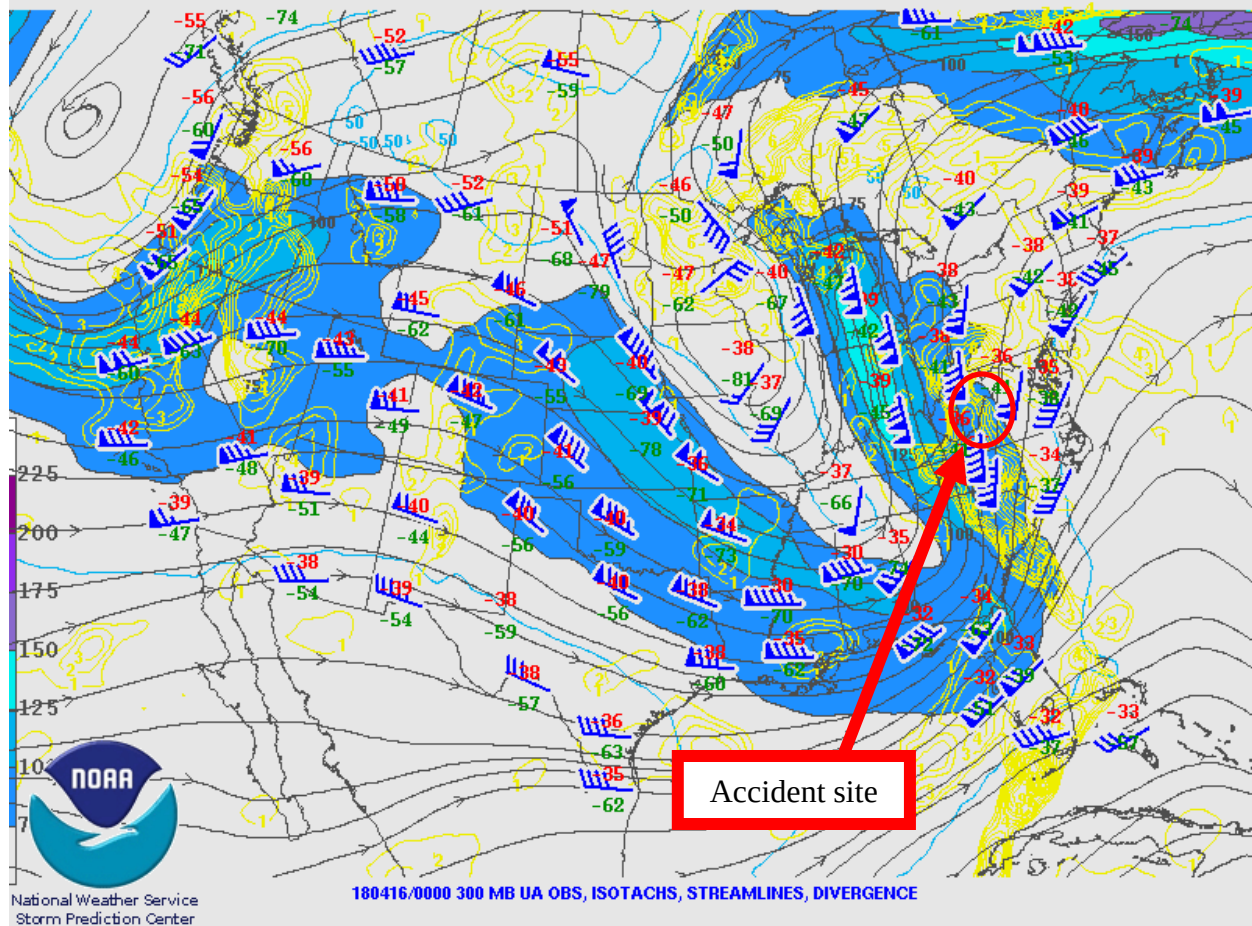


Figure 6 – 300-hPa Constant Pressure Chart for 2000 EDT

2.0 SPC Products

The SPC issued the following Day 1 Convective Outlook at 1640 EDT (figure 7) that identified areas of thunderstorms forecast for the accident site and a marginal risk that those thunderstorms would become severe. The accident site was located in an area where the SPC forecasted a 2 percent chance of a tornado within 25 miles of a point (figure 8) and a 5 to 10 percent chance of damaging thunderstorm winds or wind gusts 50 knots or greater within 25 miles of a point (figure 9). These severe thunderstorm chances were above normal compared to climatology for April, but not unusual for mid-April in the Mid-Atlantic region:

SPC AC 152040

Day 1 Convective Outlook CORR 1
NWS Storm Prediction Center Norman OK
0340 PM CDT Sun Apr 15 2018

Valid 152040Z - 161200Z

...THERE IS AN ENHANCED RISK OF SEVERE THUNDERSTORMS ACROSS PORTIONS
OF SC...NC INTO VA...

...THERE IS A SLIGHT RISK OF SEVERE THUNDERSTORMS SURROUNDING THE ENHANCED RISK FROM CENTRAL AND SOUTHERN VA TO CENTRAL FL...

...THERE IS A MARGINAL RISK OF SEVERE THUNDERSTORMS SURROUNDING THE SLIGHT RISK FROM THE UPPER OHIO VALLEY TO MIDDLE-ATLANTIC STATES AND SOUTH TO SOUTH FL...

CORRECTED GENERAL THUNDERSTORM GRAPHIC LINES.

...SUMMARY...

A line of strong to severe thunderstorms will move northeast across the Southeast and Mid-Atlantic States through tonight. Damaging winds and tornadoes are most likely from eastern South Carolina into Virginia through early evening.

...VA/Carolinas to FL...

The ongoing severe-weather threat will persist the rest of this afternoon into the evening across portions of the Carolinas and VA to coastal GA, and across the FL Peninsula. The western portions of the categorical and severe probabilities have been trimmed, given the eastward progression of the squall line.

Day 1 forecast reasoning remains valid with this outlook issuance. At mid-late afternoon, mosaic radar imagery showed a nearly continuous squall line extending from southwest VA through western NC to the GA coast into northeast FL. The northeast FL into adjacent southeast GA portion of the line developed along an apparent pre-frontal corridor of ascent. Meanwhile, portions of the long-lived Gulf of Mexico band of storms moved into the coastal areas of the central FL Gulf Coast toward mid afternoon, and will continue to approach south FL and the Keys. Discrete storms had formed in the warm sector across parts of eastern SC and central and eastern NC, with this trend expected to continue as the large upper trough approaching the Day 1 severe risk areas becomes more negatively tilted.

...Parts of northern VA, MD to the Delmarva Peninsula...

No changes with the northeast portion of the marginal risk, as strong to severe storms will be possible across these areas as the cold front advances through this region later this evening into the overnight. The backdoor cold front that was analyzed south of the lower Potomac River this afternoon is expected to advance north this evening and tonight as a warm front through at least southern, central and eastern MD, and the Delmarva Peninsula. Modifying environment just ahead of the cold front could prove favorable for strong winds and perhaps a tornado threat.

..Peters.. 04/15/2018

.PREV DISCUSSION... /ISSUED 1148 AM CDT Sun Apr 15 2018/

...North Florida to the Delmarva vicinity...

The base of a prominent upper trough centered over the Midwest will continue to steadily spread northeastward over the Tennessee Valley toward the central/southern Appalachians with ample downstream height falls and a considerable strengthening of south-southwesterly

winds through a deep layer. Persistent cloud cover and relatively weak mid-level level lapse rates will hinder robust destabilization, but this will be compensated by an increasingly moist air mass in conjunction with strengthening deep-layer/low-level shear.

At midday, a nearly continuous squall line continues to intensify across east Georgia into north Florida while other bands of storms have more recently increased across the western Carolinas. Largely unidirectional/boundary-parallel wind profiles will initially limit the eastward progression of the convective bands, but northeastward-racing bowing segments are likely to evolve over time with some net east/northeastward acceleration. Damaging winds will likely be the most common impact, but some tornadoes can be expected given the degree of low-level SRH coincident with a moist environment. At least some severe risk may develop into the Delmarva vicinity late tonight within a weakly unstable/highly sheared environment.

...Central/South Florida...

While the region will be influenced by more modest mid-level height falls and weaker deep-layer shear, an approaching squall line over the Gulf of Mexico will pose some severe risk while additional development could occur via the east-coast sea breeze. Damaging winds will exist along with the possibility of a tornado.

...Ohio Valley...

Modest moisture and minimal buoyancy may be sufficient for a few strong updrafts/downdrafts capable of localized severe in relatively close proximity to the surface low track.

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

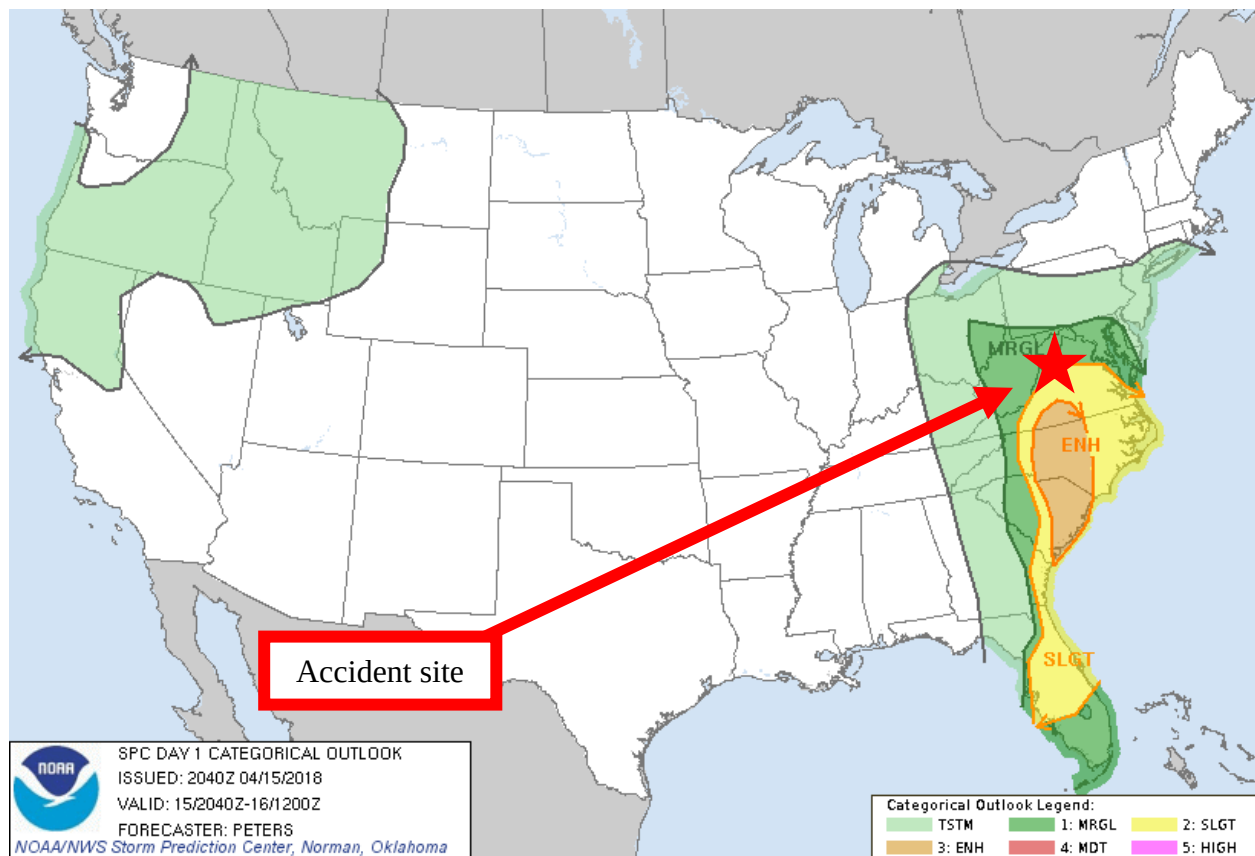


Figure 7 – SPC day 1 Convective Outlook valid at the time of the accident

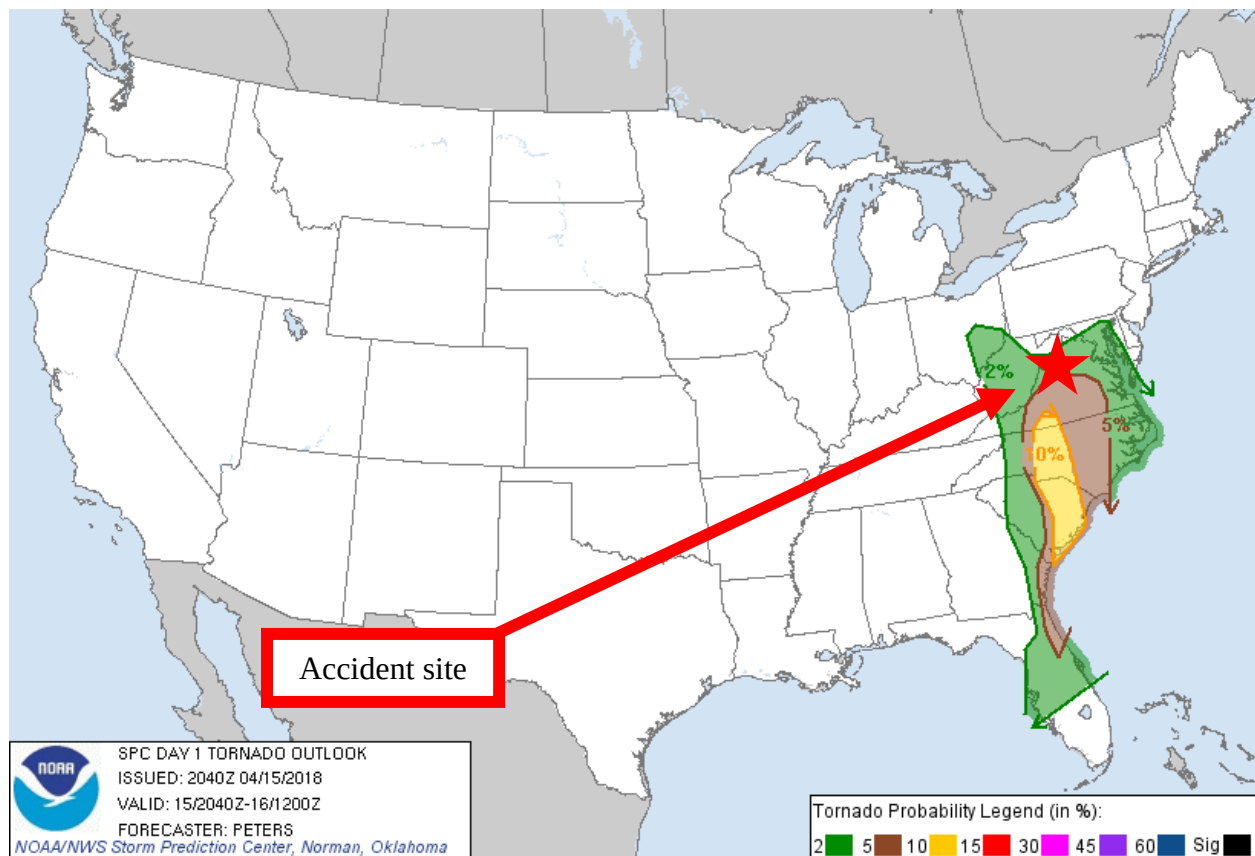


Figure 8 – SPC day 1 Tornado Outlook valid at the time of the accident

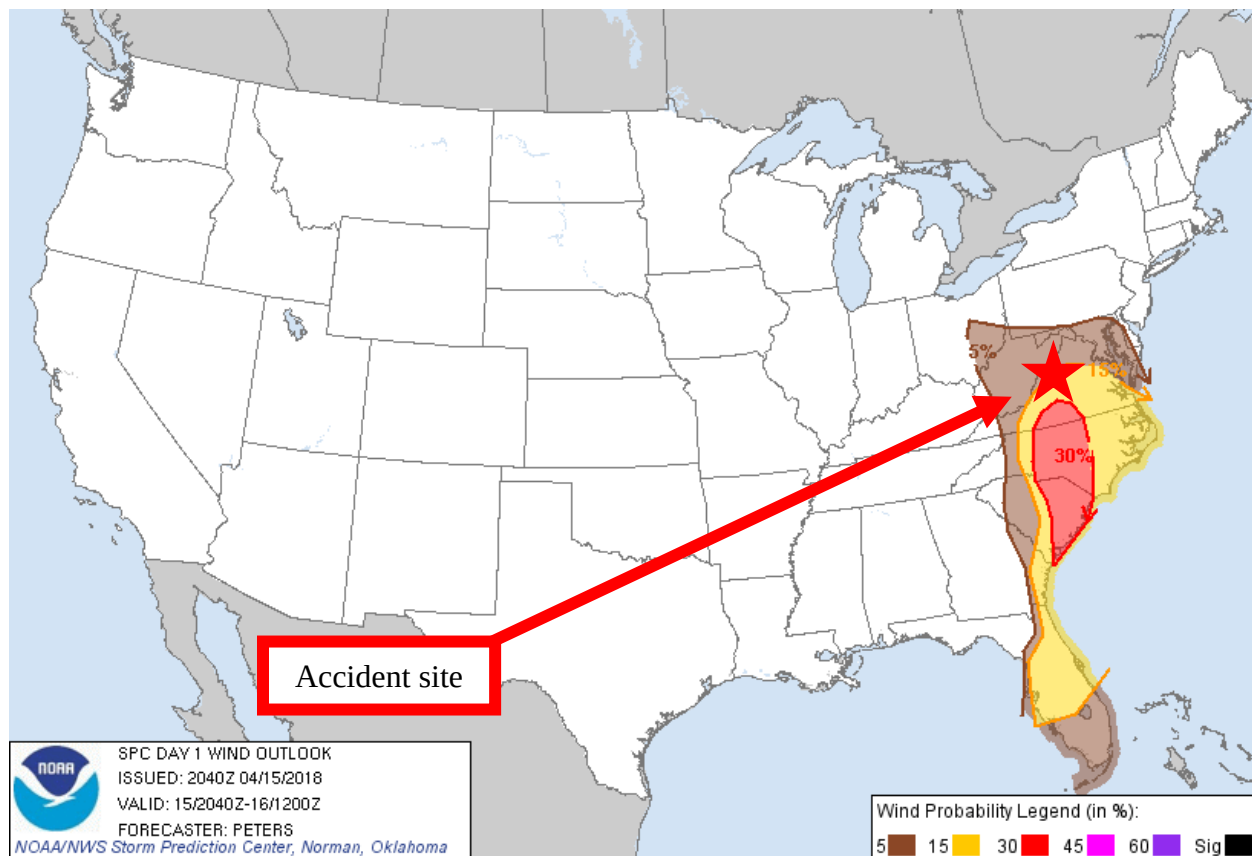


Figure 9 – SPC day 1 Wind Outlook valid at the time of the accident

3.0 Surface Observations

The area surrounding the accident site was documented using official Meteorological Aerodrome Reports (METARs) and Specials (SPECIs). Figure 10 is a sectional chart with the accident site and the closest weather reporting locations to the accident site marked.

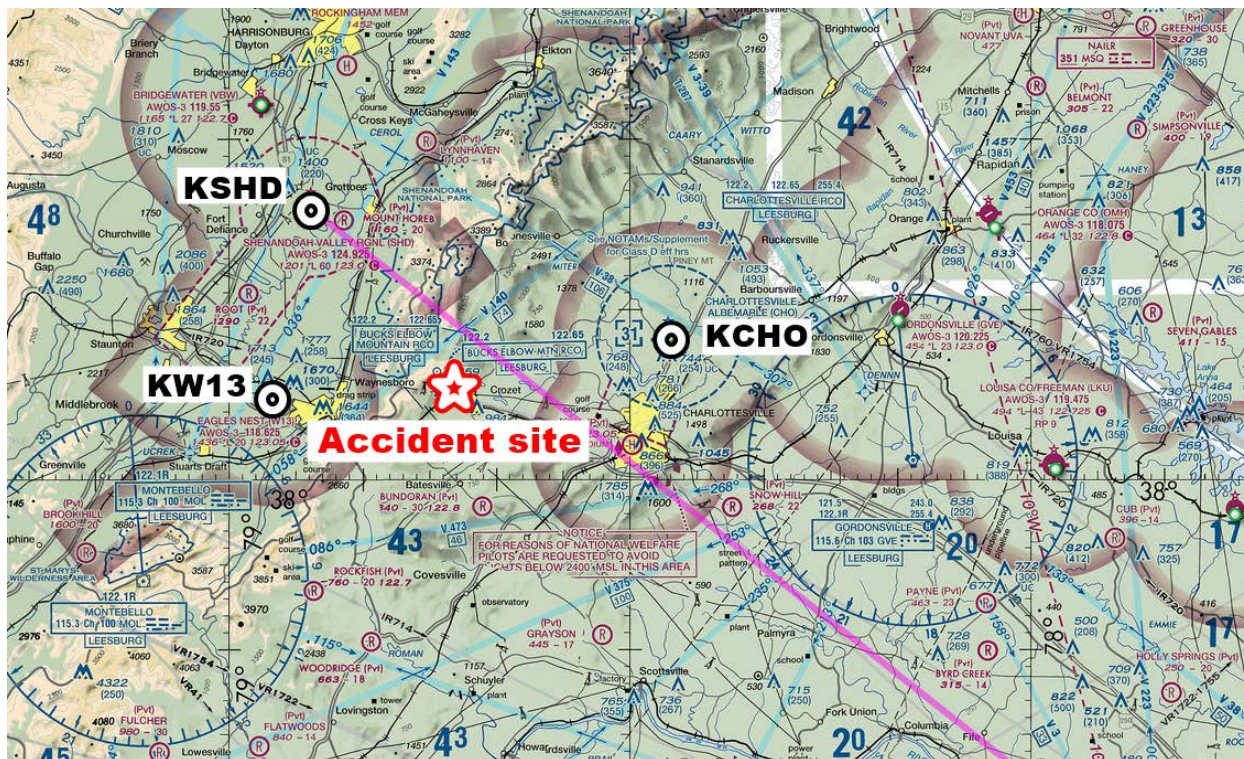


Figure 10 – Sectional chart of accident area with the location of the accident site, the closest surface observation sites, and the direct route of flight from departure to intended destination (pink line)

Eagle's Nest Airport (KW13) had the closest official weather observation point to the accident site, and was located 3 miles west of Waynesboro, Virginia. KW13 had an Automated Weather Observing System (AWOS⁴) whose reports were not supplemented. KW13 was located 11 miles west of the accident site, at an elevation of 1,436 ft, and had a 9° westerly magnetic variation⁵ (figure 10). The following observations were taken and disseminated during the times surrounding the accident:⁶

[1915 EDT] METAR KW13 152315Z AUTO 02004KT 10SM BKN010 BKN016 OVC022
14/14 A2972 RMK AO1 T01410135=

[1935 EDT] METAR KW13 152335Z AUTO 09008KT 060V120 5SM BKN010 BKN022
OVC036 14/14 A2971 RMK AO1 P0005 T01440143=

[1955 EDT] METAR KW13 152355Z AUTO 00000KT 4SM BKN008 BKN022 OVC042
14/13 A2973 RMK AO1 P0016 60035 T01350134 10232 20135=

⁴ 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.

⁵ Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from <http://www.airnav.com/airport/W13>

⁶ Bolded sections in this report highlight information that directly reference the weather conditions that affected the accident location around the accident time.

[2015 EDT] METAR KW13 160015Z AUTO 26008G24KT 240V300 4SM BKN006 BKN016 OVC034 13/13 A2977 RMK AO1 P0010 T01320131=

[2035 EDT] METAR KW13 160035Z AUTO 04003KT 7SM SCT006 BKN016 OVC044 14/14 A2974 RMK AO1 P0014 T01370136=

ACCIDENT TIME 2054 EDT

[2055 EDT] METAR KW13 160055Z AUTO 11006KT 7SM SCT005 BKN016 OVC025 13/13 A2973 RMK AO1 P0019 T01340133=

[2115 EDT] METAR KW13 160115Z AUTO 10006KT 5SM SCT005 OVC018 12/12 A2973 RMK AO1 P0005 T01240123=

[2135 EDT] METAR KW13 160135Z AUTO 07007KT 4SM SCT005 OVC016 12/12 A2972 RMK AO1 P0015 T01160116=

[2155 EDT] METAR KW13 160155Z AUTO 10007KT 3SM BKN016 BKN023 OVC039 12/11 A2971 RMK AO1 P0026 T01150113=

KW13 weather at 2015 EDT, automated, wind from 260° at 8 knots with gusts to 24 knots, wind varying between 240° and 300°, 4 miles visibility, broken ceiling at 600 ft above ground level (agl), broken skies at 1,600 ft agl, overcast skies at 3,400 ft agl, temperature of 13° Celsius (C), dew point temperature of 13° C, and an altimeter setting of 29.77 inches of mercury. Remarks, station without a precipitation discriminator, 0.10 inches of precipitation since 1955 EDT, temperature 13.2° C, dew temperature 13.1° C.

KW13 weather at 2035 EDT, automated, wind from 040° at 3 knots, 7 miles visibility, scattered clouds at 600 ft agl, broken ceiling at 1,600 ft agl, overcast skies at 4,400 ft agl, temperature of 14° C, dew point temperature of 14° C, and an altimeter setting of 29.74 inches of mercury. Remarks, station without a precipitation discriminator, 0.14 inches of precipitation since 1955 EDT, temperature 13.7° C, dew temperature 13.6° C.

KW13 weather at 2055 EDT, automated, wind from 110° at 6 knots, 7 miles visibility, scattered clouds at 500 ft agl, broken ceiling at 1,600 ft agl, overcast skies at 2,500 ft agl, temperature of 13° C, dew point temperature of 13° C, and an altimeter setting of 29.73 inches of mercury. Remarks, station without a precipitation discriminator, 0.19 inches of precipitation since 1955 EDT, temperature 13.4° C, dew temperature 13.3° C.

KW13 weather at 2115 EDT, automated, wind from 100° at 6 knots, 5 miles visibility, scattered clouds at 500 ft agl, overcast ceiling at 1,800 ft agl, temperature of 12° C, dew point temperature of 12° C, and an altimeter setting of 29.73 inches of mercury. Remarks, station without a precipitation discriminator, 0.05 inches of precipitation since 2055 EDT, temperature 12.4° C, dew temperature 12.3° C.

Shenandoah Valley Regional Airport (KSHD) was the next closest official weather observation point to the accident site as well as being the intended destination airport. KSHD had an AWOS whose reports were not supplemented. KSHD was located 13 miles northwest of the accident site, at an elevation of 1,201 ft, and had a 9° westerly magnetic variation⁷ (figure 10). The following observations were taken and disseminated during the times surrounding the accident:

[1915 EDT] METAR KSHD 152315Z AUTO 08010KT 10SM -RA OVC029 15/13 A2975
RMK AO2 T01450126=

[1935 EDT] METAR KSHD 152335Z AUTO 00000KT 5SM +RA BKN016 OVC027 14/13
A2975 RMK AO2 P0008 T01400126=

[1955 EDT] METAR KSHD 152355Z AUTO 07006KT 4SM +RA SCT009 OVC014 14/13
A2975 RMK AO2 LTG DSNT SE P0020 60054 T01370125 10236 20137=

**[2015 EDT] METAR KSHD 160015Z AUTO 05005KT 4SM +VCTSRA BKN008 OVC014
13/13 A2977 RMK AO2 P0012 T01340125=**

**[2035 EDT] METAR KSHD 160035Z AUTO 35012KT 7SM RA SCT009 BKN047 OVC050
11/11 A2977 RMK AO2 LTG DSNT SE P0029 T01110105=**

ACCIDENT TIME 2054 EDT

**[2055 EDT] METAR KSHD 160055Z AUTO 01009KT 10SM RA BKN020 BKN042 OVC048
10/10 A2976 RMK AO2 LTG DSNT E P0034 T01040099=**

**[2115 EDT] METAR KSHD 160115Z AUTO 03009KT 10SM RA SCT007 BKN018 OVC034
10/10 A2976 RMK AO2 P0004 T01000096=**

[2135 EDT] METAR KSHD 160135Z AUTO 02007KT 5SM +RA BKN007 BKN018 OVC035
10/10 A2975 RMK AO2 P0014 T01000096=

[2155 EDT] METAR KSHD 160155Z AUTO 03008KT 7SM RA OVC003 10/10 A2973
RMK AO2 P0021 T01010098=

KSHD weather at 2015 EDT, automated, wind from 050° at 5 knots, 4 miles visibility, vicinity⁸ thunderstorms and heavy rain, broken ceiling at 800 ft agl, overcast skies at 1,400 ft agl, temperature of 13° C, dew point temperature of 13° C, and an altimeter setting of 29.77 inches of mercury. Remarks, station with a precipitation discriminator, 0.12 inches of precipitation since 1955 EDT, temperature 13.4° C, dew temperature 12.5° C.

⁷ Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from <http://www.airnav.com/airport/KSHD>

⁸ In the vicinity of the airport is defined as a weather phenomenon within 5-10 miles of the airfield, but not over the airfield.

KSHD weather at 2035 EDT, automated, wind from 350° at 12 knots, 7 miles visibility, moderate rain, scattered clouds at 900 ft agl, broken ceiling at 4,700 ft agl, overcast skies at 5,000 ft agl, temperature of 11° C, dew point temperature of 11° C, and an altimeter setting of 29.77 inches of mercury. Remarks, station with a precipitation discriminator, lightning distant⁹ southeast, 0.29 inches of precipitation since 1955 EDT, temperature 11.1° C, dew temperature 10.5° C.

KSHD weather at 2055 EDT, automated, wind from 010° at 9 knots, 10 miles visibility or greater, moderate rain, broken ceiling at 2,000 ft agl, broken skies at 4,200 ft agl, overcast skies at 4,800 ft agl, temperature of 10° C, dew point temperature of 10° C, and an altimeter setting of 29.76 inches of mercury. Remarks, station with a precipitation discriminator, lightning distant east, 0.34 inches of precipitation since 1955 EDT, temperature 10.4° C, dew temperature 9.9° C.

KSHD weather at 2115 EDT, automated, wind from 030° at 9 knots, 10 miles visibility or greater, moderate rain, scattered clouds at 700 ft agl, broken ceiling at 1,800 ft agl, overcast skies at 3,400 ft agl, temperature of 10° C, dew point temperature of 10° C, and an altimeter setting of 29.76 inches of mercury. Remarks, station with a precipitation discriminator, 0.04 inches of precipitation since 2055 EDT, temperature 10.0° C, dew temperature 9.6° C.

Charlottesville-Albemarle Airport (KCHO) was the next closest airport to the accident site with official weather information. KCHO had an Automated Surface Observing System (ASOS¹⁰) whose reports were supplemented by air traffic control (ATC) when the KCHO ATC tower was in operation. KCHO was located 13 miles east-northeast of the accident site, at an elevation of 640 ft, and had an 8° westerly magnetic variation¹¹ (figure 10). The following observations were taken and disseminated during the times surrounding the accident:

[1953 EDT] METAR KCHO 152353Z 04018KT 10SM -RA OVC006 12/11 A2975 RMK
AO2 WSHFT 2303 LTG DSNT S AND SW RAB2255E13B45 SLP070
P0001 60001 T01220106 10272 20122 58015=
[2013 EDT] SPECI KCHO 160013Z 04019G25KT 7SM VCTS OVC006 12/11 A2974
RMK AO2 PK WND 03026/2359 LTG DSNT SE-W RAE03 P0000 T01170106=
[2026 EDT] SPECI KCHO 160026Z 05017G23KT 1 3/4SM VCTS +RA BR OVC005
12/11 A2975 RMK AO2 PK WND 04028/0014 LTG DSNT SE
AND S RAE03B17 P0014 T01170106=
[2028 EDT] SPECI KCHO 160028Z 06014G23KT 2SM +RA BR OVC005 12/11 A2976
RMK AO2 PK WND 04028/0014 LTG DSNT SE AND S RAE03B17
P0015 T01170106=

⁹ Distant indicated that the lightning was beyond 10 miles but less than 30 miles from the center of the airport (or airport location point, ALP).

¹⁰ ASOS – Automated Surface Observing System is equipped with meteorological instruments to observe and report wind, visibility, ceiling, temperature, dewpoint, altimeter, and barometric pressure.

¹¹ Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from <http://www.airnav.com/airport/KCHO>

[2036 EDT] SPECI KCHO 160036Z 05017G22KT 1 3/4SM VCTS +RA BR BKN005
OVC013 11/11 A2976 RMK AO2 PK WND 04028/0014 LTG
DSNT E-S RAE03B17 P0026 T01110106=

**[2045 EDT] SPECI KCHO 160045Z VRB06G23KT 1 1/2SM +RA BR SCT005 OVC019
11/11 A2979 RMK AO2 PK WND 04028/0014 LTG DSNT E-S
RAE03B17 PRESRR P0042 T01110106=**

**[2053 EDT] METAR KCHO 160053Z 03006KT 1 1/2SM +RA BR SCT007 OVC015 11/11
A2978 RMK AO2 PK WND 04028/0014 LTG DSNT NE-S RAE03B17
SLP082 P0050 T01110106=**

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**[2057 EDT] SPECI KCHO 160057Z 02004KT 2 1/2SM RA BR BKN007 OVC015 11/11
A2979 RMK AO2 LTG DSNT NE-S P0001 T01110106=**

**[2112 EDT] SPECI KCHO 160104Z 04012KT 4SM RA BR BKN007 BKN017 OVC046
11/10 A2976 RMK AO2 LTG DSNT E AND SE PRESFR P0003 T01110100=**

[2126 EDT] SPECI KCHO 160126Z 03014KT 5SM -RA BR SCT007 BKN044 OVC050
11/09 A2975 RMK AO2 LTG DSNT NE AND SE P0008 T01110094=

[2140 EDT] SPECI KCHO 160140Z 04014KT 6SM RA BR BKN006 BKN035 OVC050
11/09 A2976 RMK AO2 LTG DSNT E AND SE P0010 T01110094=

KCHO weather at 2045 EDT, variable wind at 6 knots with gusts to 23 knots, one and a half miles visibility, heavy rain and mist, scattered clouds at 500 ft agl, an overcast ceiling at 1,900 ft agl, temperature of 11° C, dew point temperature of 11° C, and an altimeter setting of 29.79 inches of mercury. Remarks: automated station with a precipitation discriminator, peak wind from 040° at 28 knots at 2014 EDT, lightning distant east through south, rain ended at 2003 EDT, rain began at 2017 EDT, pressure rising rapidly, 0.42 inches of precipitation since 1953 EDT, temperature 11.1° C, dew point temperature 10.6° C.

KCHO weather at 2053 EDT, wind from 030° at 6 knots, one and a half miles visibility, heavy rain and mist, scattered clouds at 700 ft agl, an overcast ceiling at 1,500 ft agl, temperature of 11° C, dew point temperature of 11° C, and an altimeter setting of 29.78 inches of mercury. Remarks: automated station with a precipitation discriminator, peak wind from 040° at 28 knots at 2014 EDT, lightning distant northeast through south, rain ended at 2003 EDT, rain began at 2017 EDT, sea-level pressure 1008.2 hPa, 0.50 inches of precipitation since 1953 EDT, temperature 11.1° C, dew point temperature 10.6° C.

KCHO weather at 2057 EDT, wind from 020° at 4 knots, 2 and a half miles visibility, moderate rain and mist, a broken ceiling at 700 ft agl, overcast skies at 1,500 ft agl, temperature of 11° C, dew point temperature of 11° C, and an altimeter setting of 29.79 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant northeast through south, 0.01 inches of precipitation since 2053 EDT, temperature 11.1° C, dew point temperature 10.6° C.

KCHO weather at 2112 EDT, wind from 040° at 12 knots, 4 miles visibility, moderate rain and mist, a broken ceiling at 700 ft agl, broken skies at 1,700 ft agl, overcast skies at 4,600 ft agl, temperature of 11° C, dew point temperature of 10° C, and an altimeter setting of 29.76 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant east and southeast, pressure falling rapidly, 0.03 inches of precipitation since 2053 EDT, temperature 11.1° C, dew point temperature 10.0° C.

The observations from KW13, KSHD, and KCHO surrounding the accident time indicated IFR¹² conditions, with moderate to heavy rain, and distant lightning to the northeast through south of the accident site. Ceiling were observed as low as 600 ft agl and visibilities as low as one and a half miles with the heavy rain. Lightning information will be further reviewed in section 6.5.

4.0 Upper Air Data

The closest official upper air sounding to the accident site was from Roanoke, Virginia, (KRNK), located 96 miles southwest of the accident site, with a site number 72318, and a station elevation of 2,126 ft. The 2000 EDT KRNK sounding was plotted on a standard Skew-T Log P diagram¹³ with the derived stability parameters included in figure 11 (with data from the surface to 600-hPa, or approximately 14,000 ft msl.) This data was analyzed using the RAOB¹⁴ software package. The sounding depicted the lifted condensation level (LCL)¹⁵ at the surface, the level of free convection (LFC)¹⁶ at the surface, and the convective condensation level (CCL)¹⁷ at 2,541 ft agl. The sounding had a greater than 85% relative humidity from the surface through 14,000 ft. The freezing level was at 10,976 ft msl. The precipitable water value was 1.27 inches.

¹² Instrument Flight Rules (IFR) – Refers to the general weather conditions pilots can expect at the surface. IFR criteria means a ceiling below 1,000 ft agl and/or less than 3 miles visibility.

¹³ 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.

¹⁴ RAOB – (The complete Rawinsonde Observation program) is an interactive sounding analysis program developed by Environmental Research Services, Matamoras, Pennsylvania.

¹⁵ LCL - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.

¹⁶ 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.

¹⁷ 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.

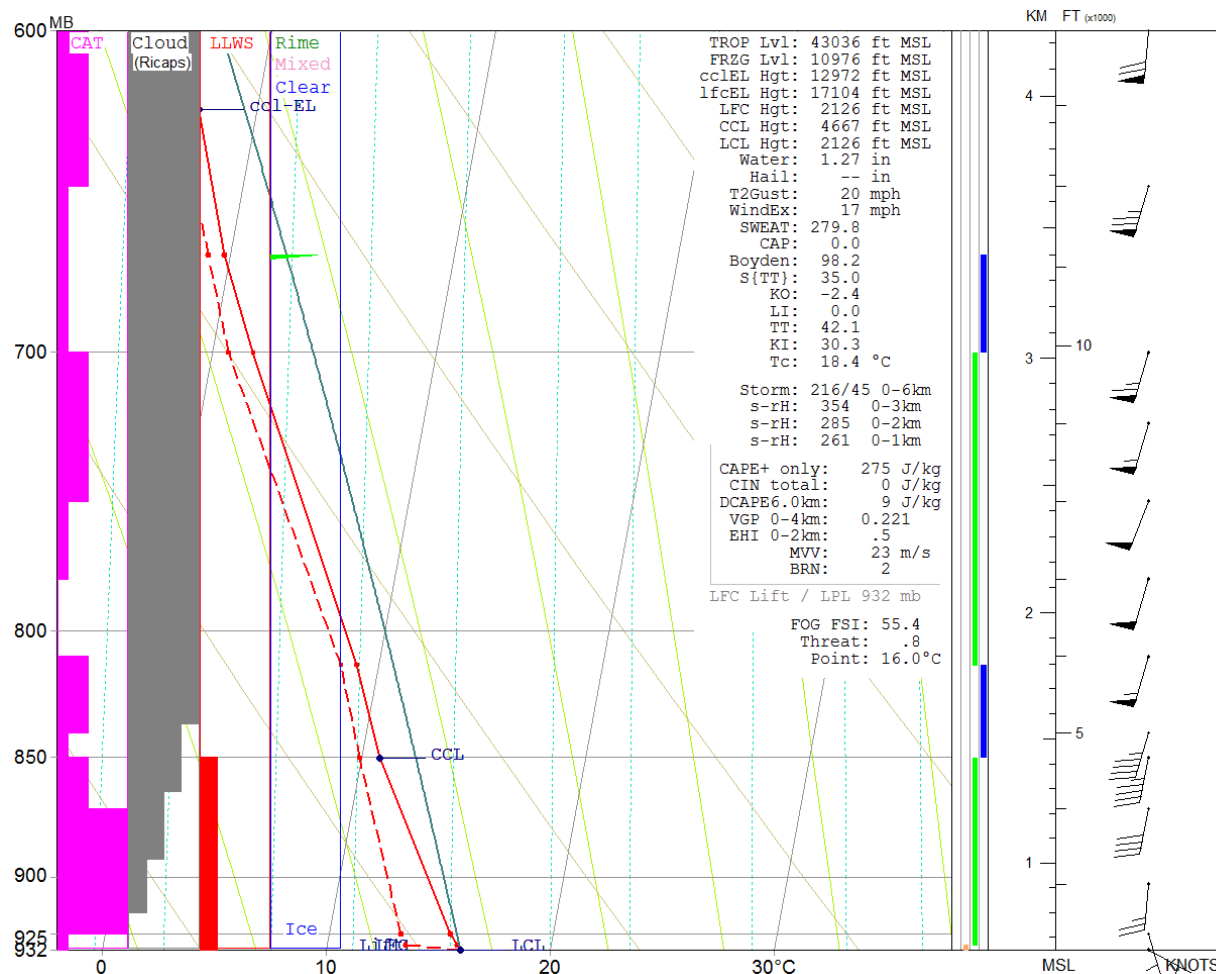


Figure 11 – 2000 EDT KRNK sounding

The 2000 EDT KRNK sounding indicated an alternating conditionally unstable and stable environment from the surface through 14,000 ft with 275 Joules/kilogram (J/kg) of CAPE¹⁸. The Maximum vertical velocity (MVV) for this atmosphere was calculated as 23 meters/second (about 4,528 ft per minute).¹⁹ Downdraft CAPE (DCAPE; 6 kilometers agl)²⁰ was measured at 9 J/kg. RAOB identified the possibility of clouds between 2,500 ft msl (~ 400 ft agl) through 14,000 ft. A small layer of rime icing was indicated by RAOB at 11,500 ft.

¹⁸ 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.

¹⁹ 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.

²⁰ 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 2000 EDT KRNK sounding wind profile indicated a near-surface wind from 120° at 3 knots with the wind becoming southerly by 3,000 ft and remaining southerly or south-southwesterly through 14,000 ft. The wind increased from below 5 knots near the surface to 25 knots at 3,000 ft (~800 ft agl). The wind increased to 55 knots by 6,000 ft and then 70 knots by 14,000 ft. RAOB indicated the possibility of low-level wind shear (LLWS) outside of convective activity between the surface and 4,000 ft (~2,000 ft agl). RAOB indicated the possibility of light to extreme clear-air turbulence in several layers between the surface and 14,000 ft, the possibility of extreme clear-air turbulence in a layer between the surface and 4,000 ft (~2,000 ft agl).

5.0 Satellite Data

Infrared 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. Infrared imagery (GOES-16 band 13) at wavelengths of 10.3 microns (μm) was retrieved for the period. Satellite imagery surrounding the time of the accident, from 1800 EDT through 2300 EDT at approximately 15-minute intervals were reviewed, and the closest images to the time of the accident are documented here.

Figures 12, 13, and 14 present the GOES-16 infrared imagery from 2050, 2055, and 2100 EDT 6X magnification with the accident site highlighted with a red square. Inspection of the infrared imagery indicated cloud cover over the accident site at the accident time. The lower brightness temperatures (blue and green colors; higher cloud tops) were located above the accident site around the accident time with the cloud cover moving from south-southwest to north-northeast. Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 2000 EDT KRNK sounding, the approximate cloud-top heights over the accident site were 35,000 ft at 2055 EDT. It should be noted these figures have not been corrected for any parallax error.

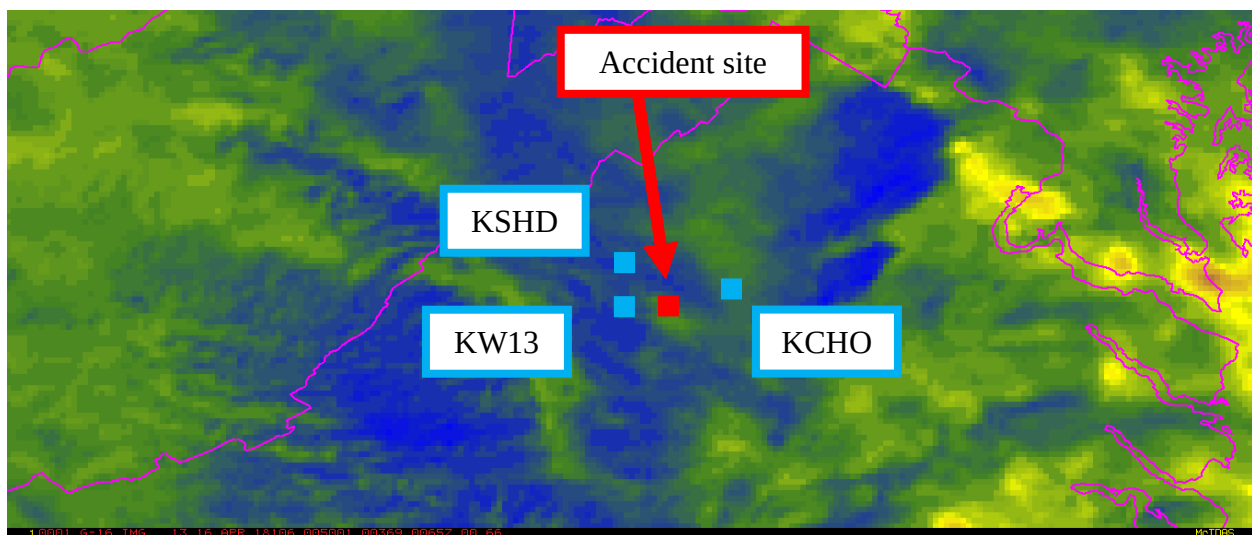


Figure 12 – GOES-16 infrared image at 2050 EDT

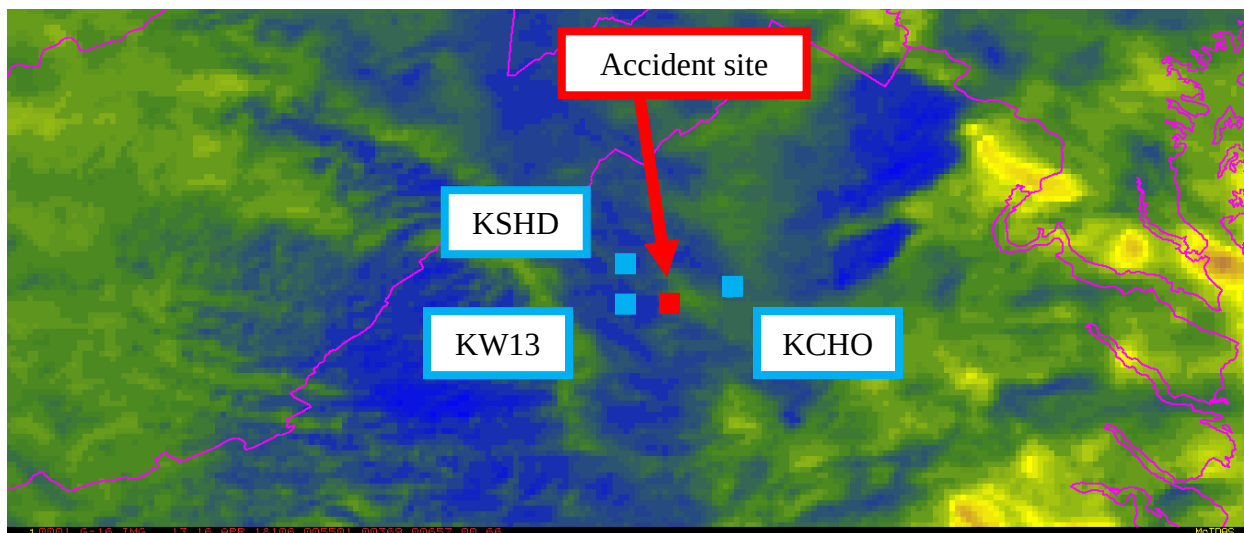


Figure 13 – GOES-16 infrared image at 2055 EDT

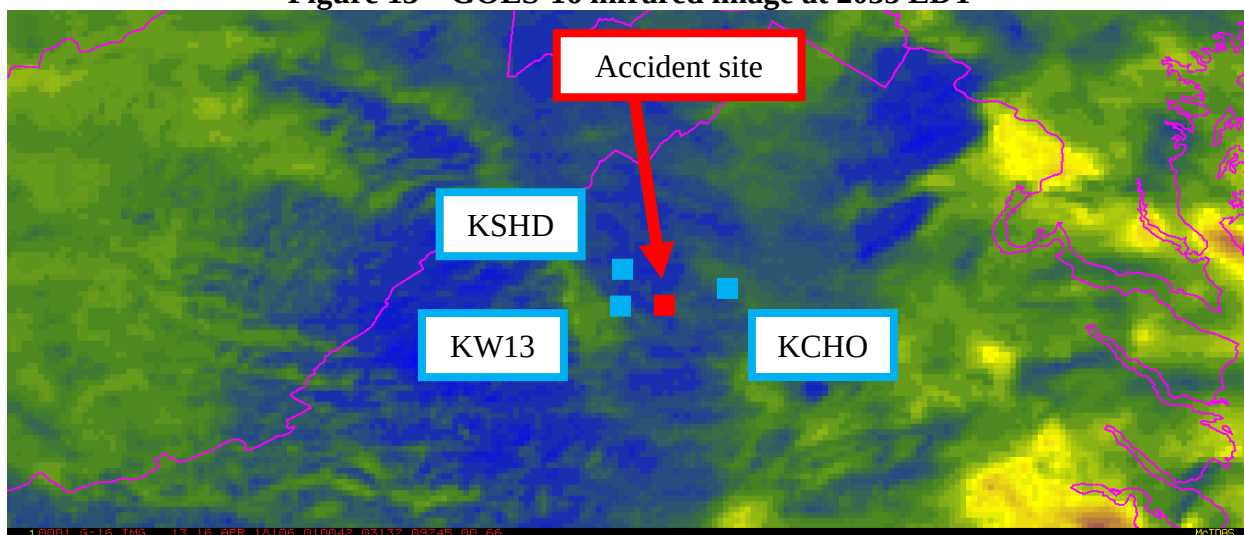


Figure 14 – GOES-16 infrared image at 2100 EDT

6.0 Radar Imagery Information

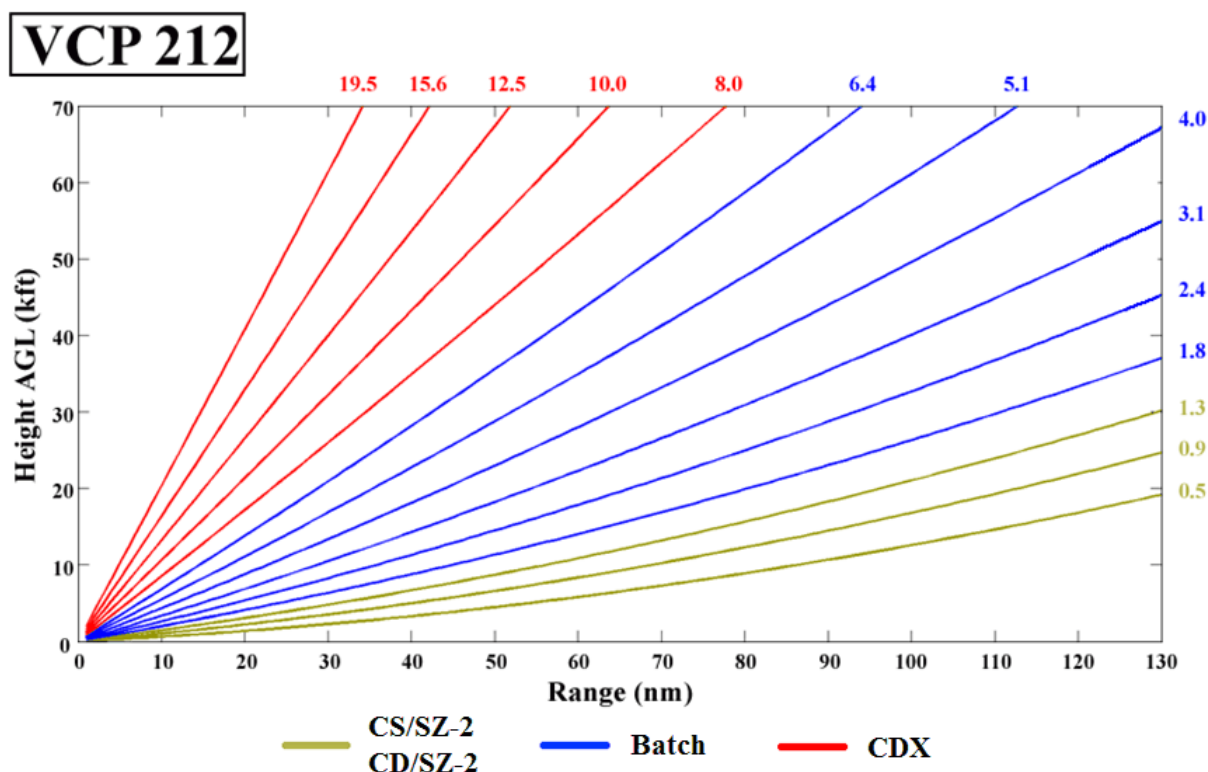
The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)²¹ to the accident site was the Sterling, Virginia, radar (KLWX), which was located 78 miles northeast of the accident site at an elevation of 292 ft. Level II archive radar data was obtained from the NCEI utilizing the NEXRAD Data Inventory Search and displayed using the NOAA's Weather and Climate Toolkit software.

²¹ 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 14 elevation scans from 0.5° to 19.5° every four and 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 KLWX WSR-88D radar was operating in the precipitation mode (Mode A, 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.



VCP-212 Precipitation Mode Scan Strategy²²

²² 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)

6.2 Beam Height Calculation

Assuming standard refraction²³ of the WSR-88D radar beam, and considering a beamwidth²⁴ 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
0.5°	8,840 ft	4,990 ft	12,690 ft

Based on the radar height calculations, the 0.5° elevation scan depicted the conditions between 4,990 ft and 12,690 ft msl over the accident site and these scans “saw” the closest altitudes to the accident site before the accident occurred.

6.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors²⁵ 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 decibels (dBZ²⁶), and is a general measure of echo intensity. FAA Advisory Circular AC 00-24C²⁷, “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.

WO – Without range unfolding (WO)

²³ Standard Refraction in the atmosphere is when the temperature and humidity distributions are approximately average, and values set at the standard atmosphere.

²⁴ Beamwidth - the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum value.

²⁵ 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.

²⁶ 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.

²⁷

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

- 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 Regional Weather Radar Summary

Figure 15 provides a radar summary image from 2045 EDT with reflectivity values over the mid-Atlantic United States. The accident site was located in an area of 20 to 45 dBZ values at 2045 EDT. These reflectivity values indicated light to heavy echoes at the accident site around the accident time.

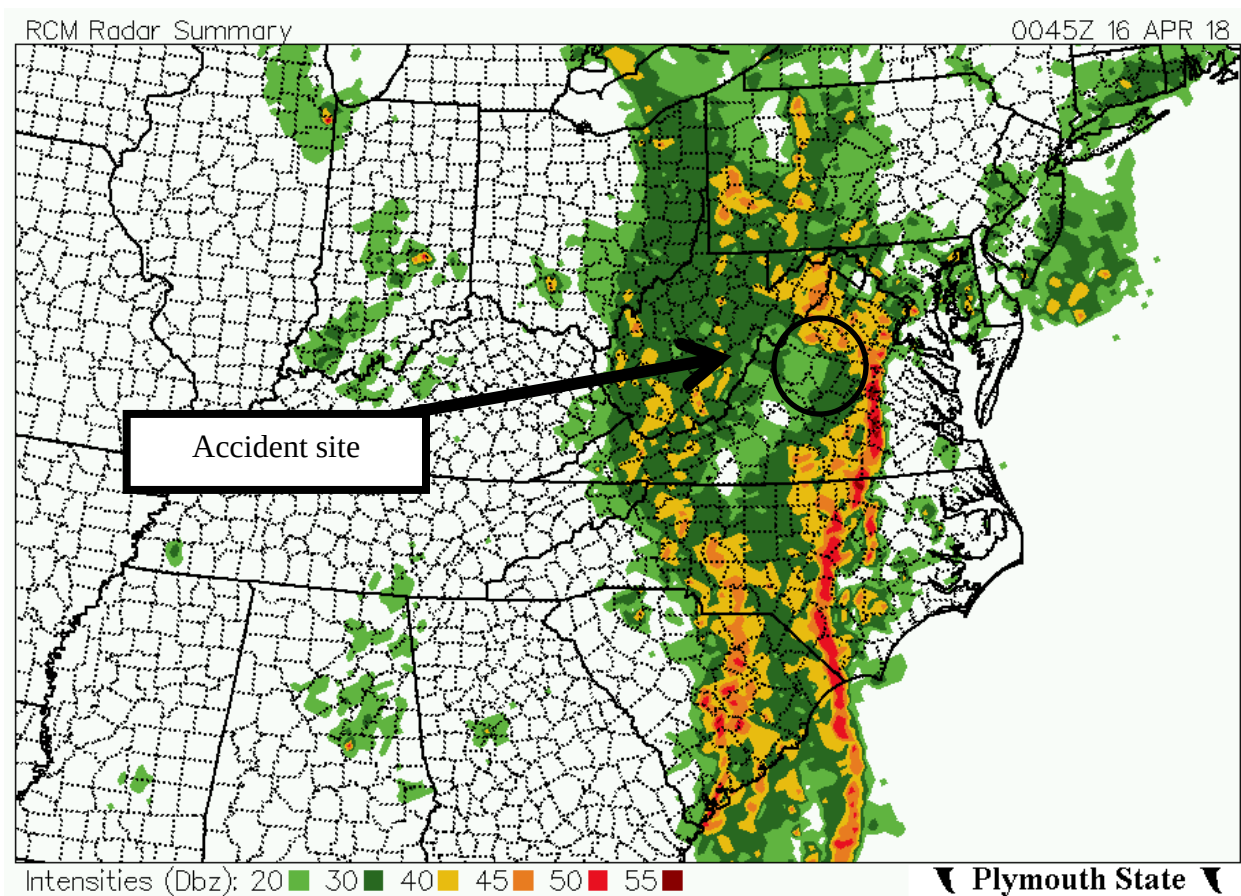


Figure 15 – Radar summary image for 2045 EDT with the accident site area circled

6.5 Base Reflectivity and Lightning Data

Figures 16, 17, 18, 19, and 20 present the KLWX WSR-88D base reflectivity images for the 0.5° elevation scans initiated at 2037, 2042, 2047, 2053, and 2058 EDT, respectively, with a resolution of 0.5° X 250 m. Reflectivity values between 25 and 35 dBZ were located above the accident site at 2053 EDT which corresponded to the surface observation precipitation reports from KW13, KSHD, and KCHO (section 3.0). The reflectivity bands were moving from south-southwest to north-northeast between 2004 and 2103 EDT (attachment 1). The reflectivity targets indicated moderate to heavy rain moving northward across the accident site at the accident time.

There were no lightning strikes within 10 miles of the accident site around the accident time. However, the accident flight did fly through a thunderstorm line between 2042 and 2047 EDT (figures 17 and 18), with several lightning flashes²⁸ within 3 miles²⁹ of the aircraft.³⁰ There were 914 lightning flashes and strikes between 2030 and 2055 EDT for the area bounded by figures 16 through 20.

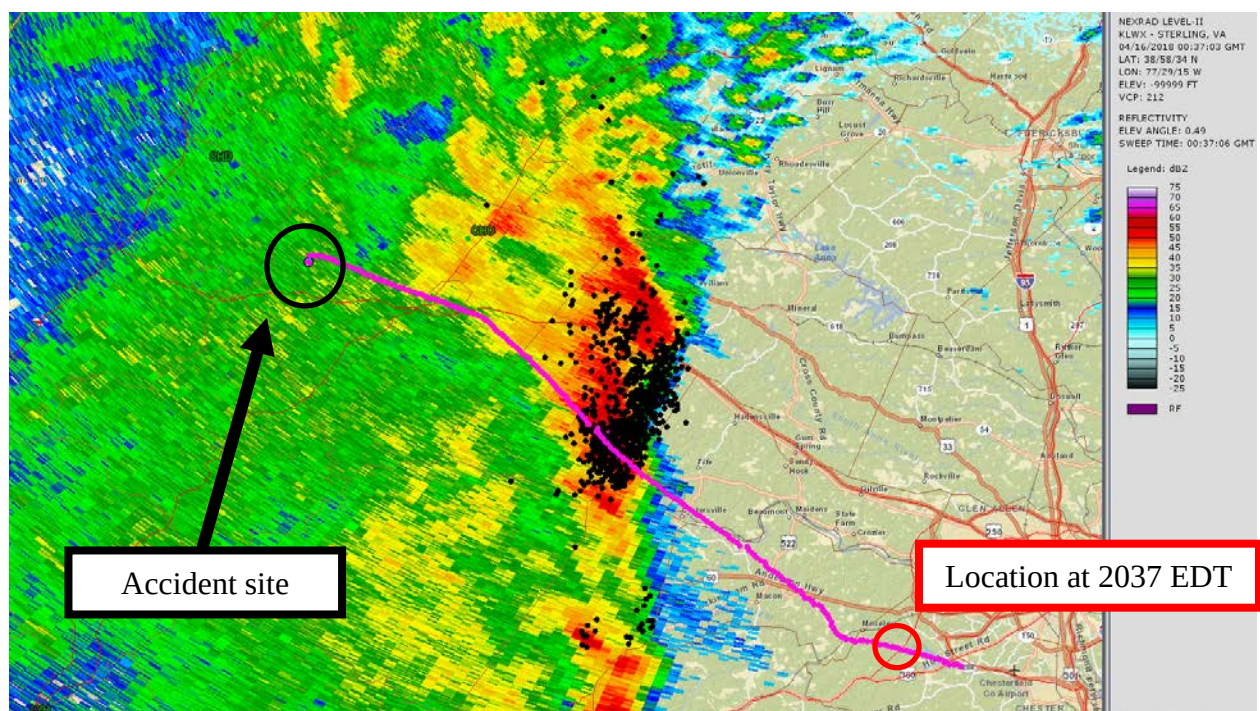


Figure 16 – KLWX WSR-88D reflectivity for the 0.5° elevation scan initiated at 2037 EDT with the accident site marked with black circle, the accident flight track in pink, and the lightning flashes represented by the black dots

²⁸ 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.

²⁹ For more information please see ATC data points.

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

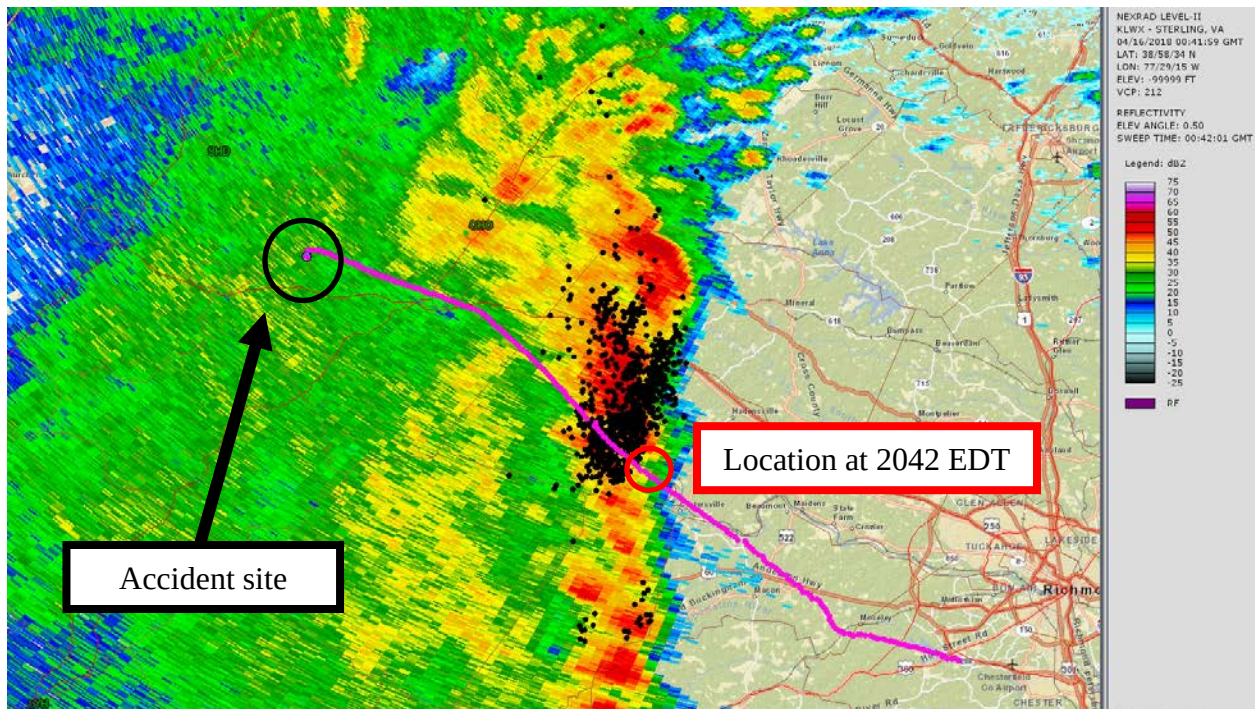


Figure 17 – KLWX WSR-88D reflectivity for the 0.5° elevation scan initiated at 2042 EDT with the accident site marked with black circle, the accident flight track in pink, and the lightning flashes represented by the black dots

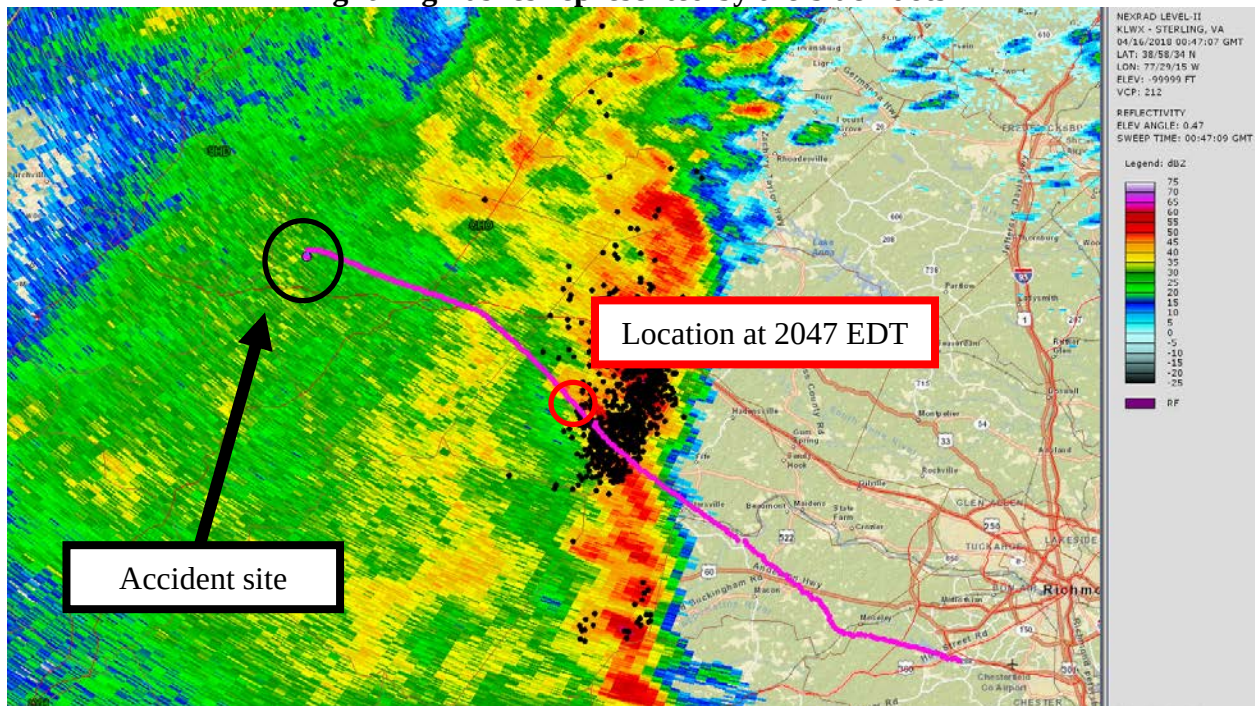


Figure 18 – KLWX WSR-88D reflectivity for the 0.5° elevation scan initiated at 2047 EDT with the accident site marked with black circle, the accident flight track in pink, and the lightning flashes represented by the black dots

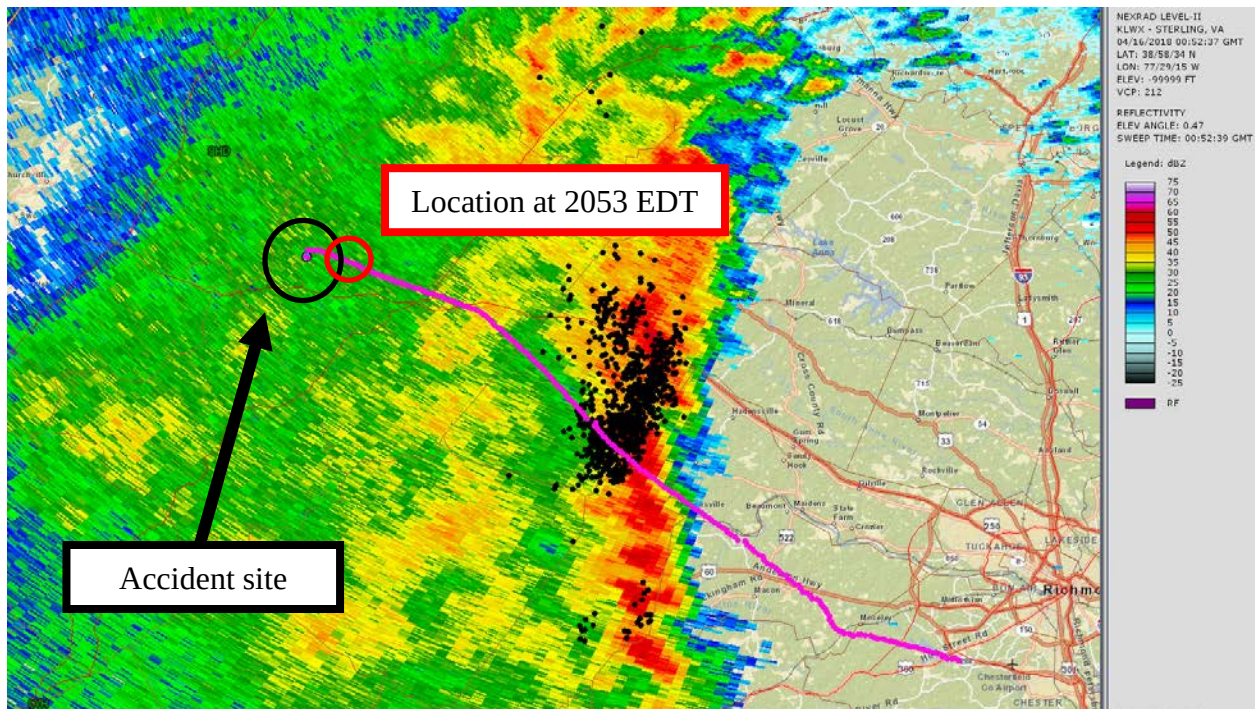


Figure 19 – KLWX WSR-88D reflectivity for the 0.5° elevation scan initiated at 2053 EDT with the accident site marked with black circle, the accident flight track in pink, and the lightning flashes represented by the black dots

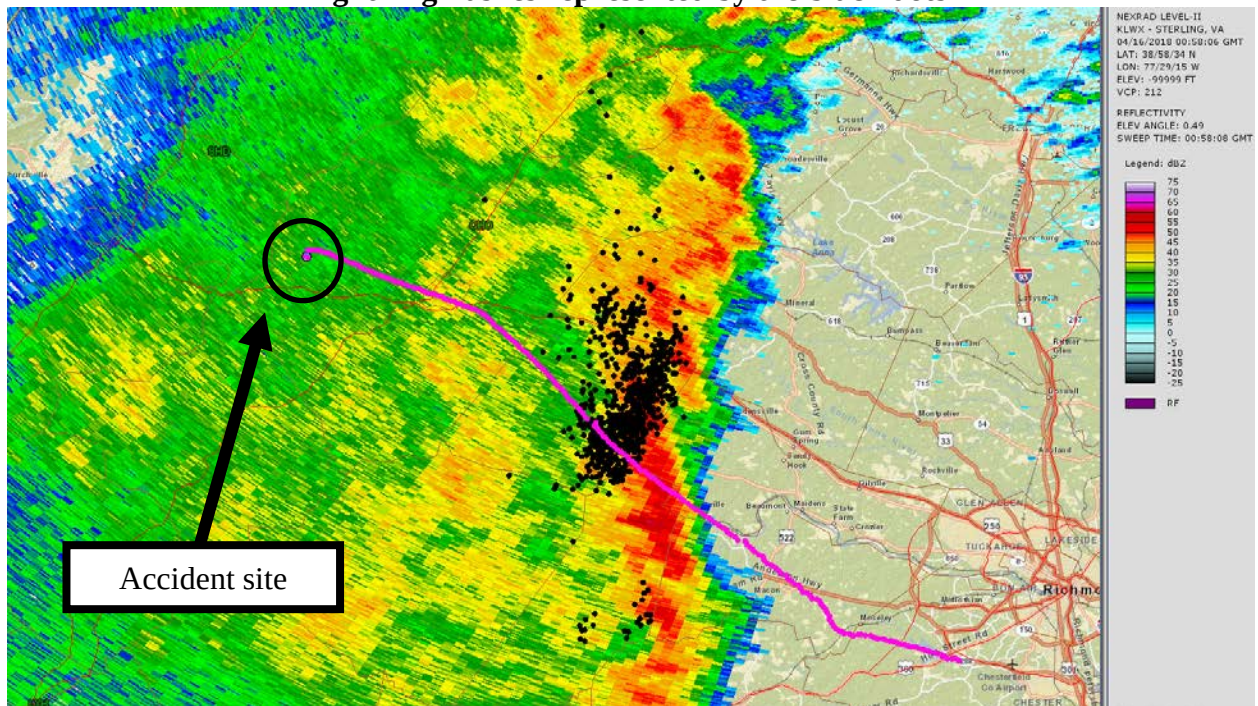


Figure 20 – KLWX WSR-88D reflectivity for the 0.5° elevation scan initiated at 2058 EDT with the accident site marked with black circle, the accident flight track in pink, and the lightning flashes represented by the black dots

7.0 Pilot Reports³¹

All PIREPs within 75 miles of the accident site from about two hours prior to the accident time to about two hours after the accident time were reviewed. Only PIREPs for below FL200³² are provided below:

CHO UUA /OV CHO210020/TM 2301/FL060/TP CRJ2/TB MOD

CHO UUA /OV CHO210010/TM 2305/FL030/TP CRJ2/TB MOD

CHO UUA /OV CHO280023/TM 0005/FL045/TP CRJ2/SK BASES 015 OVC/TB MOD

IAD UA /OV HEF/TM 0105/FL020/TP BE30/SK OVC007/RM DURD

DCA UA /OV CSN0905/TM 0147/FL190/TP B737/TB MOD

DCA UA /OV CSN3605/TM 0155/FL110/TP B737/TB MOD 140-100/RM HEAVY RAIN / LIGHTNING

Urgent pilot report (UUA), CHO; Over – 20 miles from CHO on the 210° radial; Time – 1901 EDT (2301Z); Altitude – 6,000 ft; Type aircraft – Bombardier CRJ200; Turbulence – Moderate.

Urgent pilot report (UUA), CHO; Over – 10 miles from CHO on the 210° radial; Time – 1905 EDT (2305Z); Altitude – 3,000 ft; Type aircraft – Bombardier CRJ200; Turbulence – Moderate.

Urgent pilot report (UUA), CHO; Over – 23 miles from CHO on the 280° radial; Time – 2005 EDT (0005Z); Altitude – 4,500 ft; Type aircraft – Bombardier CRJ200; Sky – Bases at 1,500 ft overcast; Turbulence – Moderate.

Routine pilot report (UA), Washington Dulles International Airport, Virginia (IAD); Over – Manassas Regional Airport, Virginia (HEF); Time – 2105 EDT (0105Z); Altitude – 2,000 ft; Type aircraft – Beechcraft Super King Air 300; Sky – Overcast skies at 700 ft; Remarks – During descent.

Routine pilot report (UA), Ronald Reagan Washington National Airport, Virginia (DCA); Over – 5 miles from Casanova, Virginia, (CSN) on the 090° radial; Time – 2147 EDT (0147Z); Altitude – FL190; Type aircraft – Boeing 737-700; Turbulence – Moderate.

Routine pilot report (UA), DCA; Over – 5 miles from CSN on the 360° radial; Time – 2155 EDT (0155Z); Altitude – 11,000 ft; Type aircraft – Boeing 737-700; Turbulence – Moderate between 14,000 and 10,000 ft; Remarks – Heavy rain and lightning.

³¹ Only pilot reports with the WMO header UBVA** and UBWV** identifier were considered.

³² 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.

8.0 SIGMET and CWSU Advisories

There were two convective Significant Meteorological Information (SIGMET) advisories valid for the accident site at the accident time (figures 21, 22, and 23). SIGMET 31E issued at 1855 EDT and valid through 2055 EDT warned of a line of severe thunderstorms with tops to FL420 with tornadoes, hail to the size of one inch, and wind gusts to 60 knots possible, with the SIGMET area moving from 210° at 40 knots (figure 21). SIGMET 36E issued at 1955 EDT and valid through 2155 EDT warned of a line of severe thunderstorms with tops to FL410 with tornadoes, hail to the size of one inch, and wind to gusts to 60 knots possible, with the SIGMET area moving from 210° at 40 knots (figure 22). There were no non-convective SIGMETs valid for the accident site at the accident time:

WSUS31 KPCI 152255
SIGE
MKCE WST 152255
CONVECTIVE SIGMET 31E
VALID UNTIL 0055Z
VA NC WV SC
FROM 20ESE EKN-RDU-FLO
**LINE SEV TS 50 NM WIDE MOV FROM 21040KT. TOPS TO FL420.
TORNADOES...HAIL TO 1 IN...WIND GUSTS TO 60KT POSS.**

WSUS31 KPCI 152355
SIGE
MKCE WST 152355
CONVECTIVE SIGMET 36E
VALID UNTIL 0155Z
VA WV
FROM 30ENE EKN-40ESE LYH
**LINE SEV TS 40 NM WIDE MOV FROM 21040KT. TOPS TO FL410.
TORNADOES...HAIL TO 1 IN...WIND GUSTS TO 60KT POSS.**

There was no Center Weather Service Unit (CWSU) Center Weather Advisories (CWA) valid at the accident site at the accident time. The Washington Air Route Traffic Control Center (ZDC ARTCC) CWSU issued a Meteorological Impact Statement (MIS) at 1556 EDT April 15 valid through 0000 EDT on April 16. The ZDC CWSU MIS warned of a line of thunderstorms, some severe, moving slowly eastward across ZDC airspace through the timeframe. The thunderstorm tops were forecast through FL300 to FL430 with some higher tops and the individual thunderstorm movement towards the northeast at 40 to 55 knots. Moderate turbulence was forecast below FL440:

FAUS20 KZDC 151956
ZDC MIS 02 VALID 152000-160400
...FOR ATC PLANNING PURPOSES ONLY...
**LINE OF TSRA...SOME SEV...WITH TOPS GENERALLY FL300-430 AND
A FEW HIGHER TOPS...MOVES SLOWLY E ACRS ZDC THRU THE PD.
INDIVIDUAL TSRA MOV NE 40-55KT. IFR CONDS CONTG NE ZDC...
INCLDG DC METROS. MOD TURB AREAS BLW FL440 ACRS ZDC.**
=

Valid at 2300 UTC 15 Apr 2018

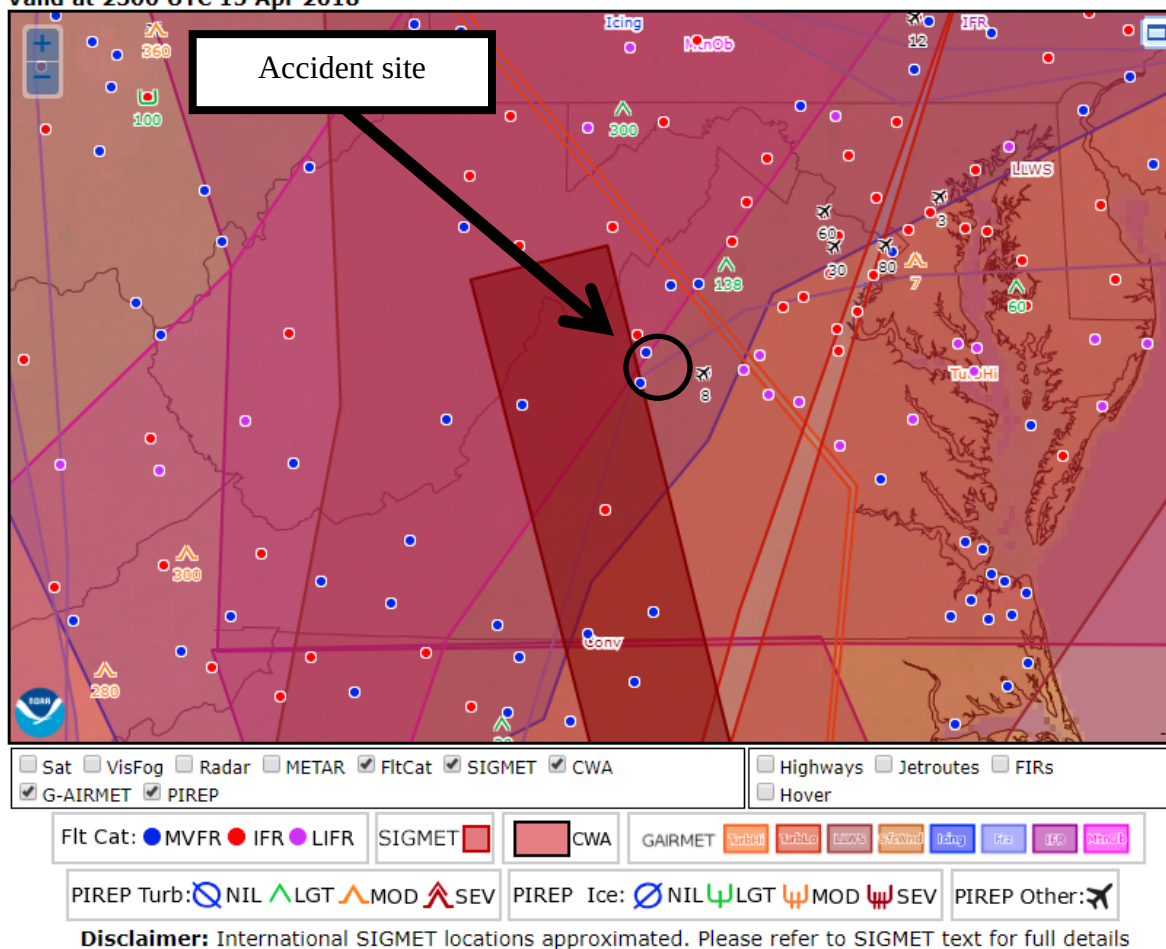


Figure 21 – AWC SIGMET, CWA, and AIRMET graphic valid for 1900 EDT

Valid at 0000 UTC 16 Apr 2018

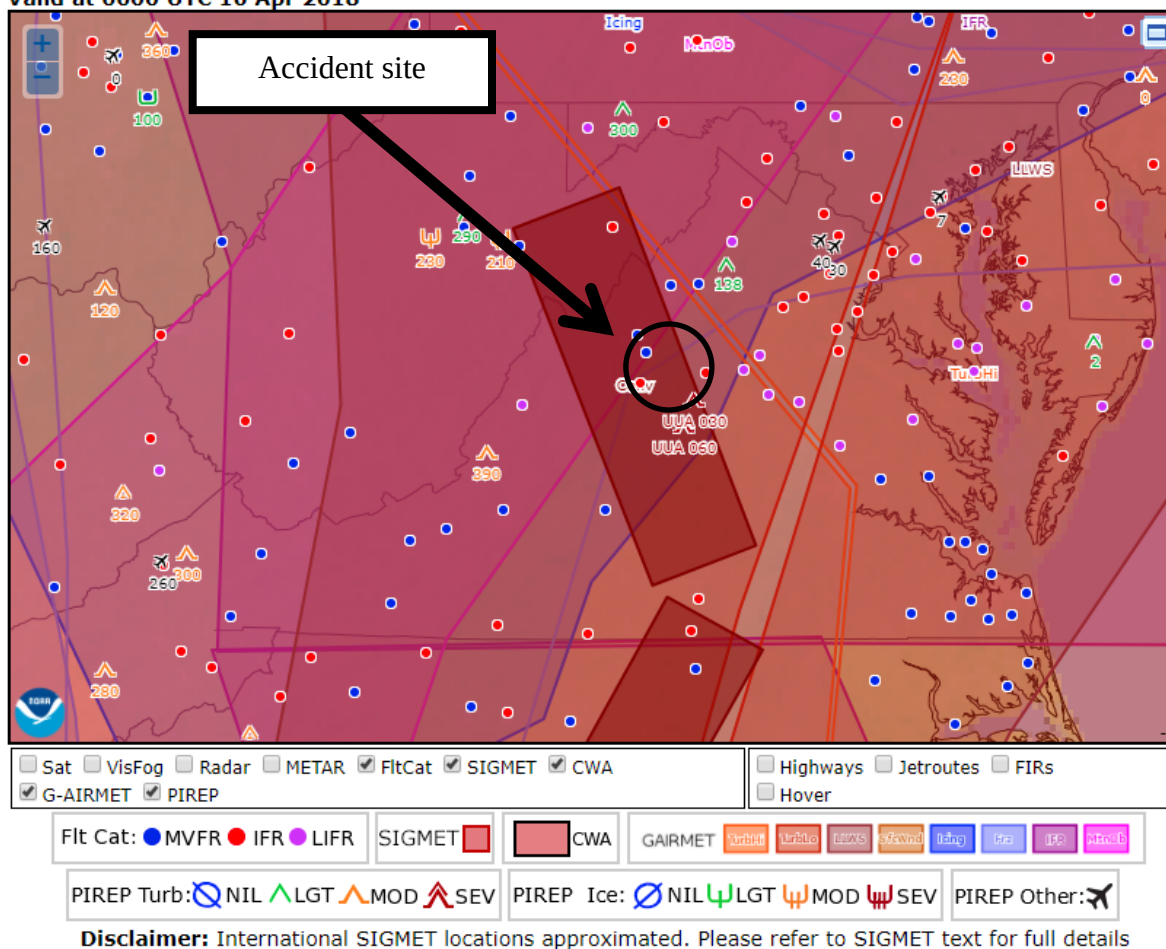


Figure 22 – AWC SIGMET, CWA, and AIRMET graphic valid for 2000 EDT

Valid at 0100 UTC 16 Apr 2018

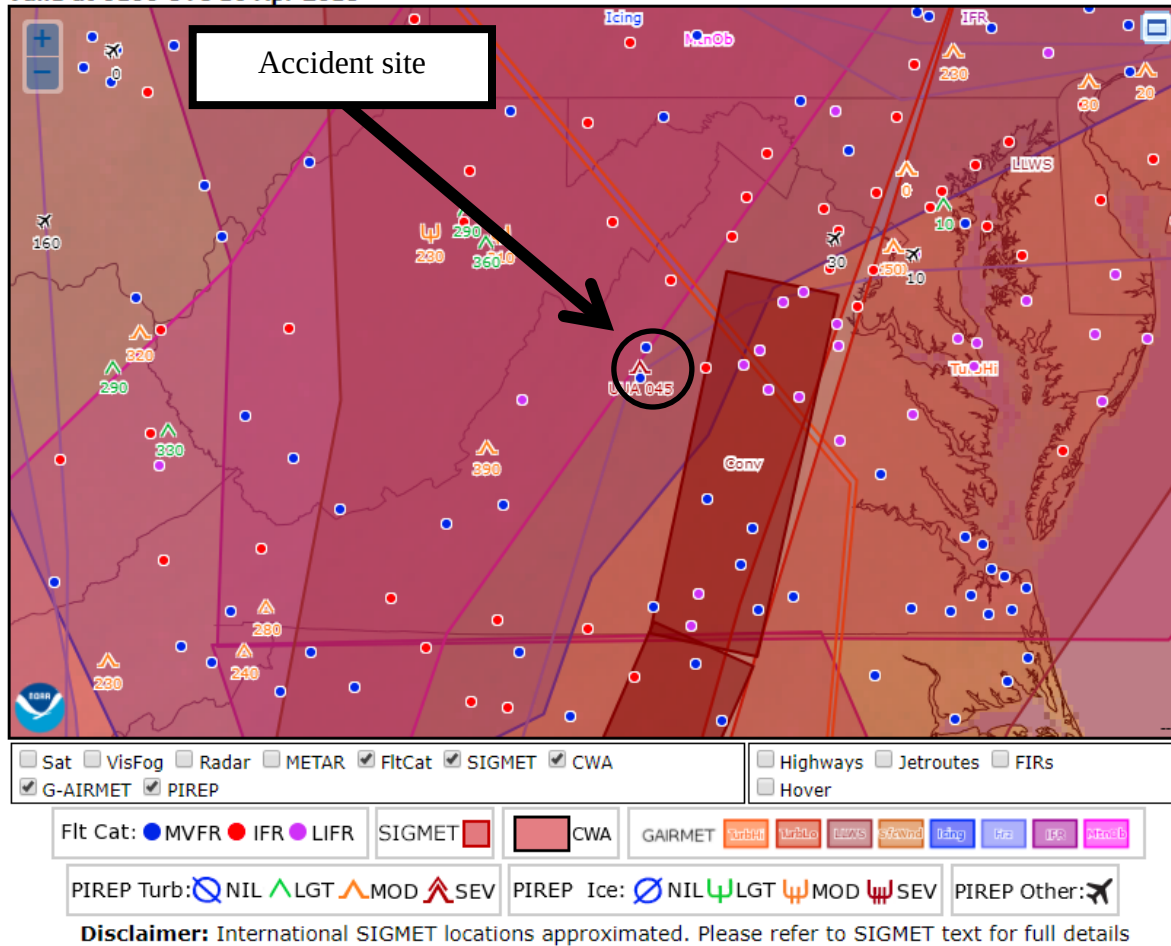


Figure 23 – AWC SIGMET, CWA, and AIRMET graphic valid for 2100 EDT

9.0 AIRMETs

There were Airmen's Meteorological Information (AIRMET)s Sierra, Tango, and Zulu that were valid for the accident site at the accident time. The AIRMETs warned of IFR conditions due to precipitation and mist, mountain obscuration conditions due to clouds, precipitation, and mist, moderate turbulence below FL180, LLWS conditions expected, and moderate icing below FL240:

WAUS41 KKCI 152220 AAA

WA1S

-BOSS WA 152220 AMD

AIRMET SIERRA UPDT 4 FOR IFR AND MTN OBSCN VALID UNTIL 160300

AIRMET IFR...ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA
AND CSTL WTRS...UPDT
FROM 90SW YOW TO 40NNW ALB TO 20SW ENE TO 140E ACK TO 200SE ACK
TO 120S ACK TO 160SE SIE TO 20NE ECG TO HNV TO HNN TO 30ESE CVG
TO FWA TO 30SSE ECK TO 90SW YOW
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG BYD 03Z THRU 09Z.

AIRMET MTN OBSCN...ME NH VT MA NY PA WV MD VA

**FROM YSC TO 40W BGR TO CON TO HAR TO 40SSE PSK TO HNV TO HNN TO
JHW TO SYR TO MSS TO YSC
MTNS OBSC BY CLDS/PCPN/BR. CONDS CONTG BYD 03Z THRU 09Z.**

.

WAUS41 KPCI 152045

WA1T

-BOST WA 152045

AIRMET TANGO UPDT 5 FOR TURB STG WNDZ AND LLWS VALID UNTIL 160300

.

AIRMET TURB...NY LO PA OH LE WV MD DC VA AND CSTL WTRS
FROM 30SE ECK TO 50W ERI TO 20S ORF TO HNV TO HNN TO CVG TO FWA
TO 30SE ECK

MOD TURB BTN FL180 AND FL410. CONDS CONTG BYD 03Z THRU 09Z.

.

AIRMET TURB...ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA
AND CSTL WTRS

FROM 40WSW YSC TO 50NNE ENE TO 50E ACK TO 240SSE ACK TO 160SE
SIE TO 20S ORF TO 50W ERI TO 20S YYY TO 60NNW SYR TO 20SSE YOW
TO 40WSW YSC

MOD TURB BTN FL290 AND FL450. CONDS CONTG BYD 03Z THRU 09Z.

.

**AIRMET TURB...NY LO PA OH LE WV MD DC VA
FROM 70NE YYY TO 30NW SYR TO 30SW ORF TO HNV TO HNN TO CVG TO
FWA TO 30SE ECK TO 70NE YYY
MOD TURB BLW FL180. CONDS CONTG BYD 03Z THRU 09Z.**

.

AIRMET TURB...ME NH VT MA RI CT NY LO NJ PA WV MD DE VA NC SC GA
FL AND CSTL WTRS

FROM 20NNW MSS TO 70ESE ENE TO 200SSE ACK TO 160SE SIE TO 190ESE
ECK TO 130SSE ILM TO 220SE CHS TO 110E OMN TO 30SW ORF TO 30NW
SYR TO 20NNW MSS

MOD TURB BLW 100. CONDS CONTG BYD 03Z THRU 09Z.

.

AIRMET STG SFC WNDZ...NY LO

FROM 50S YOW TO 20WNW SYR TO 40S YYY TO YYY TO 50S YOW

SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG BYD 03Z
ENDG 03-06Z.

.

AIRMET STG SFC WNDZ...MA RI NY NJ CSTL WTRS

FROM 50E ACK TO 120SSE ACK TO 40SE CYN TO 20WSW JFK TO 40S PVD
TO 50E ACK

SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG BYD 03Z
THRU 09Z.

.

**LLWS POTENTIAL...ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE
VA NC SC GA AND CSTL WTRS**

**BOUNDED BY 40NE MSS-20NNE ALB-20W ENE-170ENE ACK-200SE ACK-60ESE
SBY-60SSE ECG-60SSE SAV-60S AMG-40SSW SPA-30N HNN-20SW DXO-30W
BUF-20SSE YOW-40NE MSS**

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

.

OTLK VALID 0300-0900Z

AREA 1...TURB NY LO NJ PA OH LE WV MD DC DE VA NC SC GA FL AND
CSTL WTRS

BOUNDED BY 20NNW YYY-40SSW SYR-40NE SAX-160SE SIE-190ESE ECG-

130SSE ILM-170E PBI-50ESE PBI-90W EYW-90WSW PIE-40WNW ORL-40SSE
SAV-IRQ-30ENE GQO-HMV-HNN-CVG-FWA-30SE ECK-20NNW YYZ
MOD TURB BTN FL180 AND FL410. CONDS CONTG THRU 09Z.

.
AREA 2...TURB ME NH VT MA RI CT NY LO NJ PA LE WV MD DC DE VA NC
AND CSTL WTRS
BOUNDED BY 70NW PQI-60NE PQI-200SE ACK-160SE SIE-40NE SAX-40SW
SYR-20NNW YYZ-YOW-YSC-70NW PQI
MOD TURB BTN FL290 AND FL450. CONDS CONTG THRU 09Z.

.
AREA 3...TURB ME NH VT MA RI CT NY LO NJ PA MD DC DE VA NC SC GA
FL AND CSTL WTRS
BOUNDED BY 30ESE YSC-50SSE BGR-110ENE ACK-210SSE ACK-150SE SIE-
200ESE ECG-170ESE ILM-MSS-30ESE YSC
MOD TURB BLW 100. CONDS CONTG THRU 09Z.

.
AREA 4...TURB NY LO NJ PA OH LE WV MD DC DE VA NC SC GA FL AND
CSTL WTRS
BOUNDED BY MSS-170ESE ILM-130SSE ILM-120E OMN-50NNE TRV-40W TRV-
50W PIE-50S GQO-GQO-HMV-HNN-CVG-FWA-30SE ECK-20SSW YYZ-MSS
MOD TURB BLW FL180. CONDS CONTG THRU 09Z.

.
AREA 5...STG SFC WND S MD DE VA NC SC GA FL AND CSTL WTRS
BOUNDED BY 110ESE SIE-160SE SIE-190ESE ECG-130SSE ILM-220SE CHS-
140ENE OMN-70SE SAV-60ENE CHS-60SSE ECG-30ESE SBY-110ESE SIE
SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG THRU 09Z.

.
AREA 6...STG SFC WND S ME NH MA RI CT NY NJ AND CSTL WTRS
BOUNDED BY 100SSW YSJ-140E ACK-90SE ACK-90S ACK-40SE CYN-20SE
SAX-20WSW ACK-20SE ENE-80SSE BGR-100SSW YSJ
SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG THRU 09Z.

....

WAUS41 KPCI 152045
WA1Z
-BOSZ WA 152045
AIRMET ZULU UPDT 3 FOR ICE AND FRZLVL VALID UNTIL 160300

.
AIRMET ICE...ME NH VT MA NY LO AND CSTL WTRS
FROM 60WNW PQI TO 30NE PQI TO 40SSE HUL TO 160ENE ACK TO 50NE ACK
TO 40N ENE TO 40SE YSC TO 60WNW PQI
MOD ICE BLW FL220. CONDS CONTG BYD 03Z ENDG 06-09Z.

.
**AIRMET ICE...ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA
NC SC GA AND CSTL WTRS
FROM 30SE YSC TO 50NE ACK TO DCA TO 60S RIC TO 20NNW CAE TO 40WSW
ODF TO 20SSW VXV TO HMV TO HNN TO CVG TO 50E GIJ TO 30WNW CLE TO
40ESE YYZ TO 30SE YOW TO 30SE YSC
MOD ICE BTN FRZLVL AND FL240. FRZLVL SFC-130. CONDS CONTG BYD 03Z
THRU 09Z.**

.
OTLK VALID 0300-0900Z
AREA 1...ICE OH WV VA NC SC GA
BOUNDED BY HMV-20NNW IRQ-20NE LGC-GQO-HMV
MOD ICE BTN FRZLVL AND 150. FRZLVL SFC-080. CONDS DVLPG AFT 03Z.
CONDS CONTG THRU 09Z.

.
 AREA 2...ICE ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA
 NC SC AND CSTL WTRS
 BOUNDED BY 70NW PQI-30NNE PQI-110SE BGR-20SSE HTO-20NW SAX-40S
 SIE-30NNW FLO-HMV-HNN-20NNW CVG-FWA-50SW DXO-30NW CLE-30ESE
 YYZ-30SE YOW-30SSE YSC-70NW PQI
 MOD ICE BTN FRZLVL AND FL240. FRZLVL SFC-130. CONDS CONTG THRU
 09Z.

.
 FRZLVL...RANGING FROM SFC-135 ACRS AREA
 MULT FRZLVL 020-110 BOUNDED BY 20SSW DXO-20SE BKW-20E SPA-
 30NW AMG-50W TLH-50SW CEW-40W CEW-50SW PZD-GQO-HMV-HNN-CVG-
 FWA-20SSW DXO
 MULT FRZLVL BLW 130 BOUNDED BY 60ENE YSC-60WSW YSJ-140E ACK-
 90ESE ACK-EMI-40SSW JST-20ENE EWC-20SE YYZ-60SSW YOW-MSS-
 30SE YSC-60ENE YSC
 SFC ALG 20WNW YYZ-50NE BUF-50S SYR-30ESE HNK-20NE BDL-50ESE
 BGR-70SW YSJ
 040 ALG 20E CVG-40SW ROD-40NE FWA
 040 ALG 50WSW YYZ-20SSW YYZ-BUF-20NE SLT-50NW ETX-140ENE ACK
 080 ALG 20E HMV-30WNW CLE-40N CLE-ERI-20SE JST-140E ACK
 120 ALG 50NE RDU-20WNW RIC-30W SBY-110SE ACK-170SE ACK

10.0 Graphical Forecasts for Aviation

The Graphical Forecasts for Aviation (GFA) products made available before the accident time and before the accident flight departed, indicated likely (greater than 60 percent) rain showers across western Virginia, including the accident site, with surface visibilities between 1 and 5 miles (attachment 2). The GFA aviation cloud forecast indicated overcast cloud bases around 2,500 ft msl with layered clouds through 12,000 ft and cirrus clouds above for 2000 EDT (attachment 2). Higher cloud ceilings were forecast by 2300 EDT (attachment 2).

11.0 Terminal Aerodrome Forecast

KCHO had the closest NWS Terminal Aerodrome Forecast (TAF) to the accident site and the TAF issued before the accident time, but valid after the accident time, was issued at 2045 EDT and was valid for a 23-hour period beginning at 2100 EDT. The 2045 EDT TAF for KCHO was as follows:

KCHO 160045Z 1601/1624 **05017G22KT 2SM +SHRA OVC005**
 FM160300 17014G21KT 3SM +SHRA BR OVC008
 FM160800 21008KT 4SM -SHRA BR OVC010
 FM161100 26007KT P6SM OVC035
 FM161700 26011G18KT P6SM BKN045=

Between 2100 and 2300 EDT the TAF expected a wind from 050° at 17 knots with gusts to 22 knots, 2 miles visibility, heavy rain showers, and an overcast ceiling at 500 ft agl.

The KCHO TAF valid before departure and valid at the accident time was issued at 1940 EDT and was valid for a 24-hour period beginning at 2000 EDT. The 1940 EDT TAF for KCHO was as follows:

TAF KCHO 152340Z 1600/1624 **09016G24KT 4SM -SHRA OVC006**
FM160300 17014G21KT 3SM +SHRA BR VCTS OVC008CB
FM160800 21008KT 4SM -SHRA BR OVC010
FM161100 26007KT P6SM OVC035
FM161700 26011G18KT P6SM BKN045=

Between 2000 and 2300 EDT the 1940 TAF expected a wind from 090° at 16 knots with gusts to 24 knots, 4 miles visibility, light rain showers, and an overcast ceiling at 600 ft agl.

12.0 NWS Area Forecast Discussion

The NWS Office for the Baltimore/Washington area, issued the following Area Forecast Discussion (AFD) at 1532 EDT (closest AFD to the accident time with an aviation section). The aviation section of the AFD discussed widespread rain moving into the area with the rain heavy at times, some thunder possible, LLWS likely, and gusty surface winds:

569
FXUS61 KLWX 151932
AFDLWX

Area Forecast Discussion
National Weather Service Baltimore MD/Washington DC
332 PM EDT Sun Apr 15 2018

.SYNOPSIS...

A backdoor cold front will remain stalled across the area through this evening. Tonight, a strong low pressure system will move into the eastern Great Lakes, dragging a strong cold front eastward across the Mid-Atlantic by Monday morning. High pressure will gradually build back in for Tuesday and Wednesday before another low pressure system crosses the region Thursday.

&&

.NEAR TERM /THROUGH MONDAY/...

The backdoor cold front has definitely slowed to a crawl, running from south of CBE, FRR, CJR, EZF, and NUI. As warm moist air continues to lift over this boundary, showers and drizzle have been developing. Convection is developing southward from SW Virginia, and only slowly pivoting eastward due to unidirectional flow east of a deep trough. It's possible this could eventually pose a severe weather threat to the far southern portion of the area later this evening.

The upper trough will take on a negative tilt tonight. A cold front extending southward from low pressure in the Great Lakes will be moving eastward, with a triple point low developing where it intersects the backdoor front. Model consensus has this

low tracking near or just northwest of I-95, which will cause the backdoor front to lift back northward, at least into southern Maryland, and perhaps as far north as the Baltimore-Washington metro. In addition to strong deep layer shear, high helicity will be found along this frontal zone. The strong synoptic forcing will likely result in the band of moderate to heavy rain to continue eastward, with a more organized QLCS in the warm sector. Nocturnal timing and possible boundary layer stability may mitigate the severe threat, but the strong wind fields can't be ignored. Locally damaging winds and perhaps a brief tornado are the primary threats in the warm sector. The extent of the severe threat will need to be monitored through the evening, and should be east of the area by daybreak Monday (if not a few hours earlier). SPC will be monitoring trends for southeast Virginia over the next several hours as well.

The other threat is flooding. Very strong forcing from the surface front and upper trough and high PW's over 1.5" will likely lead to plenty of rainfall. Rainfall amounts generally look to be on the order of 1-3 inches, with highest amounts near and west of the Blue Ridge where orography and isentropic lift are maximized. This area is most likely to be affected by multiple rounds or extended periods of moderate to heavy rainfall before the trough takes on a negative tilt. Hi-res guidance suggests locally higher amounts are possible. Thus a Flash Flood Watch has been issued for this area where there is higher confidence in higher rain totals. This confidence trails off toward the Potomac River, with the HRRR-TL being most aggressive in probabilities of 2 inches of rain. Localized totals of 3 inches could occur across the metro, but the band of rain is generally expected to be more progressive. Flash flood guidance is also much higher outside of the urban cores. For now will continue to carry flood potential in the HWO. Lows tonight are tricky given the warm front lifting back north just ahead of the main cold front. See additional hydro details in the special section below.

Even though the front will move eastward early Monday morning, lingering showers behind the front, associated with the upper trough and wraparound moisture, will likely persist much of the day, especially in northern parts of the area. These should be much lighter, however. With temperatures cooling rapidly, especially aloft, rain will mix with and change to snow at the higher elevations, and minor accumulations may occur. Temps will probably be steady or falling much of the day.

&&

.SHORT TERM /MONDAY NIGHT THROUGH TUESDAY NIGHT/...

Upslope flow behind the surface low and deep trough aloft will combine to promote continued snow showers along the Allegheny Front into Tuesday. A few inches of snow will be possible, though the chance is low enough occurs in any 12 hour period to warrant a Winter Weather Advisory. Elsewhere, a chilly breeze will bring temps down into the 30s Monday night across much of the region, though freezing temperatures are questionable given

the winds may stay up. However, some areas in the southern Shenandoah Valley could decouple, so will mention potential freeze in the HWO. With the trough lifting out a bit and winds relaxing behind the low as it pulls further away Tuesday, clouds and upslope snow will diminish, but temps will remain quite chilly for mid April, with highs in the 40s and 50s. With a better shot of decoupling under lighter winds on Tuesday night, will have a risk of freeze in the HWO as well.

&&

.LONG TERM /WEDNESDAY THROUGH SUNDAY/...

Forecast area will be near warm frontal boundary on Wednesday. Its passage will allow for temperatures to return closer to seasonal values. Most of the day should be dry, but the highlands may see a shower late in the day.

This chance of rain will overspread the area Wednesday night and Thursday as low pressure will pass north of the area. This will place the forecast area on the warm side of the boundary. The reprieve will be short-lived, as a cold frontal passage should arrive sometime Thursday PM.

A ridge of high pressure will overspread the area for Friday and Saturday. Aside from gusty winds Friday, tranquil conditions can be expected.

&&

.AVIATION /19Z SUNDAY THROUGH FRIDAY/...

Backdoor front has stalled between Washington and CHO for now, although it's not out of the question it makes a further push south. IFR to LIFR has locked in north of the front, and will likely remain in place most of the night. Vis restrictions have developed in the deeper marine airmass at BWI and MTN, but may not occur at other terminals until more significant showers and drizzle develops toward evening. As a cold front pushes east tonight, rain will become widespread and heavy at times, some thunder is possible, and gusty winds are also a threat tonight as the front barrels through. Multiple wind shifts are possible, along with LLWS due to strong winds above the surface. Conditions improve a bit on Monday behind the front, but showers will linger, so MVFR will remain possible. Should improve to VFR Monday night and remain so thru Tuesday night as high pressure gradually builds back in.

VFR conditions should mainly prevail, with only a small chance of flight restrictions Wednesday night into Thursday.

&&

.MARINE...

Backdoor cold front has now pushed through the waters, with easterly SCA level winds being observed on all waters. Tonight, as the front lifts back north, a strong low level jet could bring gusty south winds back to portions of the waters. Have

maintained gale over waters for tonight with potential for 35+ knot gusts in heavy rain and embedded t-storms as cold front crosses the region. SCA will likely be needed Monday behind the front. Winds will gradually relax as we head through Tuesday, but the SCA will likely need to be extended for at least portions of the waters.

Anticipate backing winds Wednesday, 10 kt or less. Winds will become northwest and increase behind a cold front Thursday, possibly into SCA range.

&&

.HYDROLOGY...

Strong negatively tilted upper trough and surface cold front expected to cross region Sunday night, with widespread heavy rain and embedded t-storms. PW's rise to around 1.5", quite high for April, thanks to a very strong fetch from the Gulf and Atlantic. With the forcing and potential training, rainfall could locally exceed 3 inches in a few hours, so flooding is a concern. Flash flood guidance is lowest west of the Blue Ridge (approximately 2 inches in 3 hours), so have focused the Watch here now. The Blue Ridge could enhance rainfall as well, so will need to monitor counties just to the east. The urban areas could also experience ponding or isolated flooding, though confidence is lower in a true flash flood threat.

Most rivers should be able to handle the rainfall given recent dry conditions. The latest RFC guidance suggests the Shephardstown and Martinsburg gauges will be closest to flood stage, but this is highly contingent on QPF. River flood watches or warnings may eventually be needed.

&&

.TIDES/COASTAL FLOODING...

Water levels are near astronomical normals, though they are beginning to rise on the lower Potomac. Onshore flow followed by a strong southerly push Sunday night could lead to an influx of water causing minor flooding on late Sunday night or Monday. ESTOFS is especially strong in its surge, and SNAP-Ex ensemble takes Annapolis to near moderate flood. The greatest threat is with the Monday morning cycle, but Straits Point needs to be watched for this evening. Guidance suggests that minor flooding events could last into Monday night, maybe Tuesday.

&&

.LWX WATCHES/WARNINGS/ADVISORIES...

DC...None.

MD...None.

VA...Flash Flood Watch through late tonight for VAZ025>027-029-030-503-504-507-508.

WV...Flash Flood Watch through late tonight for WVZ055-501-502-505-506.

MARINE...Small Craft Advisory until 11 PM EDT this evening for

ANZ530>543.
Gale Warning from 11 PM this evening to 8 AM EDT Monday for
ANZ530>543.

&&

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13.0 Winds and Temperature Aloft Forecast

The NWS 1601 EDT Winds and Temperature Aloft forecast valid for the closest point to the accident site is included below:

FBUS31 KWN0 152001
FD1US1
DATA BASED ON 151800Z
VALID 160000Z FOR USE 2000-0300Z. TEMPS NEG ABV 24000

FT 3000 6000 9000 12000 18000 24000 30000 34000 39000

ROA 1645 1870+10 1976+05 2071+00 2064-11 2065-22 208237 199347 700656

The accident site was closest to the Roanoke, Virginia, (ROA) forecast point. The 1601 EDT ROA forecast for use between 1600 and 2300 EDT indicated a wind at 3,000 ft from 160° at 45 knots, a wind at 6,000 ft from 180° at 70 knots with a temperature of 10° C, and a wind at 9,000 ft from 190° at 76 knots with a temperature of 5° C.

14.0 Pilot Weather Briefing

A search of official weather briefing sources such as contract Automated Flight Service Station (AFSS) provider Leidos weather briefings and the Direct User Access Terminal Service (DUATS) was done and the accident pilot did not request a weather briefing through Leidos or DUATS.

A search of archived data from ForeFlight was done and the accident pilot did not request a weather briefing from ForeFlight. It is unknown if the accident pilot checked or received any other weather information before or during the accident flight.

15.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on April 15, 2018, indicated the following:

SUN	
Begin civil twilight	0612 EDT
Sunrise	0639 EDT
Sun transit	1315 EDT
Sunset	1951 EDT
End civil twilight	2018 EDT
Accident	2054 EDT³³

E. LIST OF ATTACHMENTS

Attachment 1 – Animation of KLWX WSR-88D reflectivity for the 0.5° elevation scan initiated between 2004 and 2103 EDT

Attachment 2 – GFA products available before the accident flight for around the accident time

Submitted by:

Paul Suffern
Senior Meteorologist

³³ Inserted accident time for reference and context.

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