**NATIONAL TRANSPORTATION SAFETY BOARD**

Office of Aviation Safety
Washington, D.C. 20594

August 29, 2018

**Factual Report**

# METEOROLOGY

CEN18FA144

## Table Of Contents

## A. ACCIDENT

Location: Near Williamsburg, Pennsylvania
Date: April 19, 2018
Time: 0843 eastern daylight time
1243 Coordinated Universal Time (UTC)
Aircraft: Cirrus SR22, Registration: N451TD

## 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 19, 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 approximate location of the accident site was at latitude 40.4228° N, longitude 78.2117° W, with an approximate elevation of 1,025 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]

### 1.1 Surface Analysis Chart

The mid-Atlantic section of the NWS Surface Analysis Chart for 0800 EDT is provided as figure 1 with the approximate location of the accident site marked within the red circle. The chart identified a surface low pressure center located east of New Jersey in the western Atlantic Ocean with a surface pressure 1002-hectopascals (hPa). Another surface low pressure center was located over southern Virginia with a surface pressure of 1006-hPa. A series of frontal boundaries stretched from the western Atlantic Ocean westward and southwestward into southeastern Virginia, then west-southwestward into central North Carolina. The accident site was located north and west of the surface low pressure centers in the cold air mass region.

The station models around the accident site depicted air temperatures in the low 30's to mid 40's degrees Fahrenheit (°F), dew point temperatures in the low 30's to low 40's °F with temperature-dew point spreads of 3° F or less, a west to north wind of 5 to 10 knots, and overcast sky cover. Light rain and mist were reported directly around the accident site with light snow reported across western Pennsylvania, Ohio, and western New York.

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

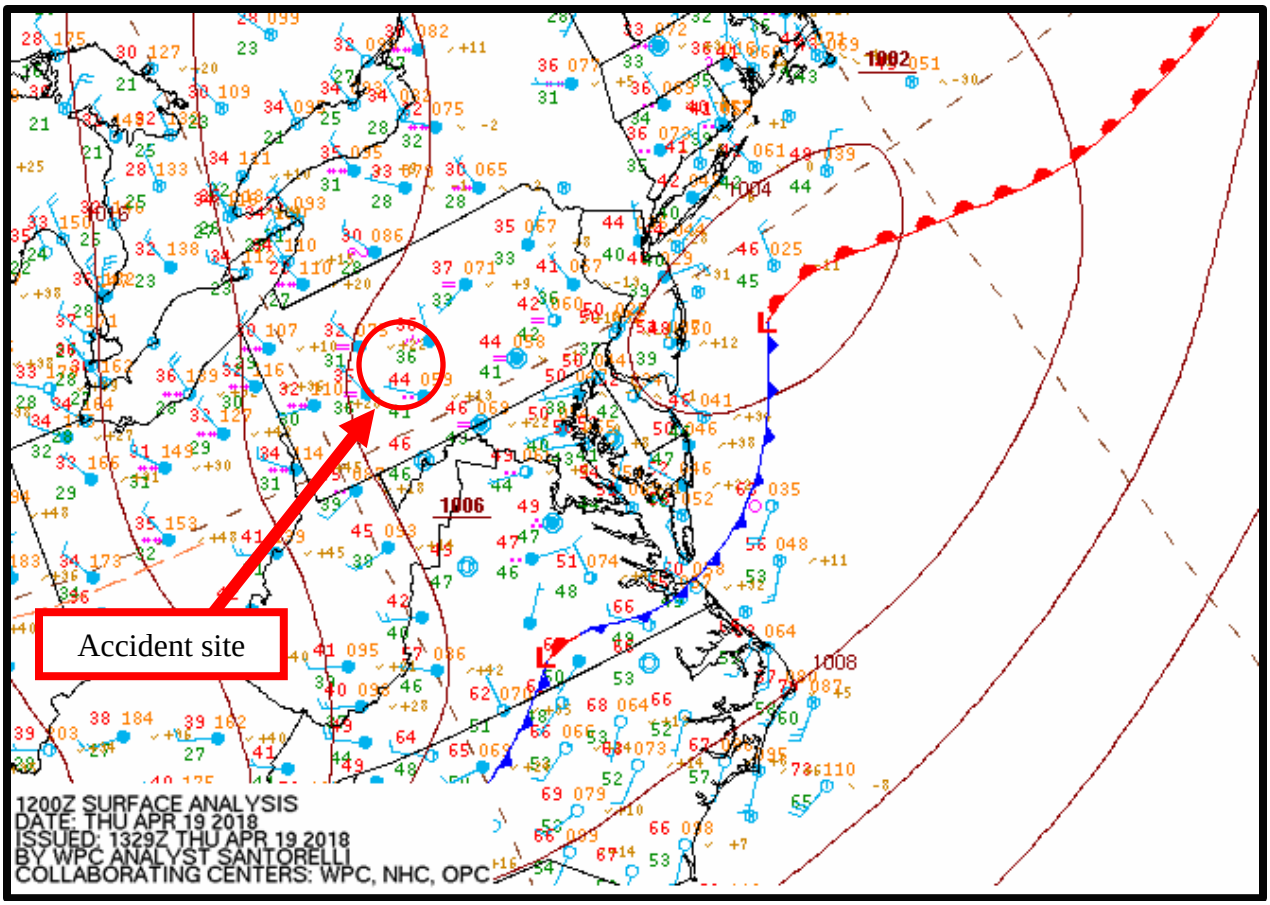



**Figure 1 – NWS Surface Analysis Chart for 0800 EDT**

## 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-level troughs[2] located on either side of the accident site (figures 3) at 850-hPa. Troughs can act as lifting mechanisms to help produce clouds and precipitation if sufficient moisture is present. There was also a mid-level trough located directly west of the accident site at 700- and 500-hPa at 0800 EDT (figures 4 and 5). There was a west-northwest wind of 15 knots at 925-hPa above the accident site with the wind becoming southwesterly by 700-hPa (figure 4) between 30 to 40 knots. By 300-hPa, the wind above the accident site was still from the southwest but increased to between 75 to 95 knots (figure 6).

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

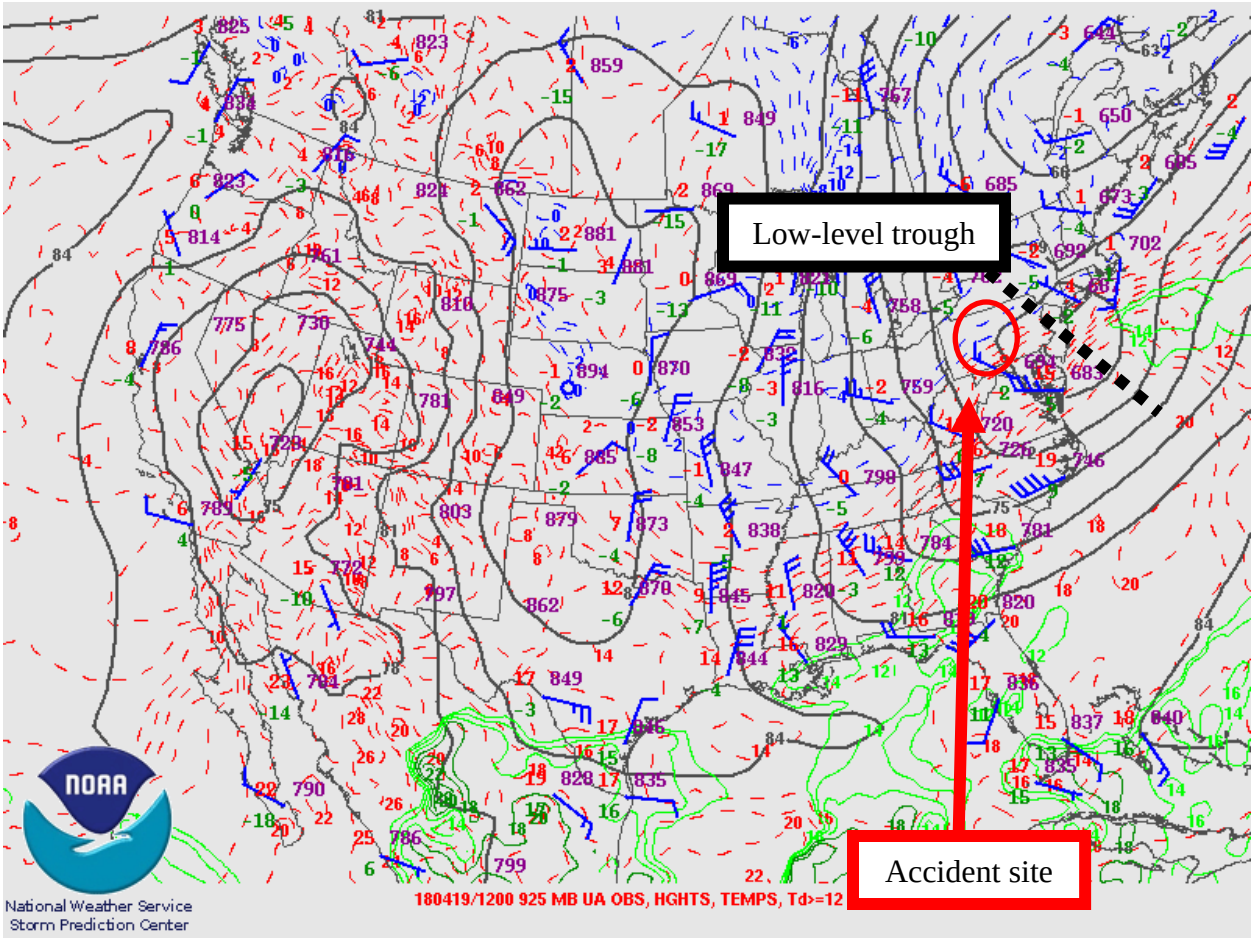



**Figure 2 – 925-hPa Constant Pressure Chart for 0800 EDT**

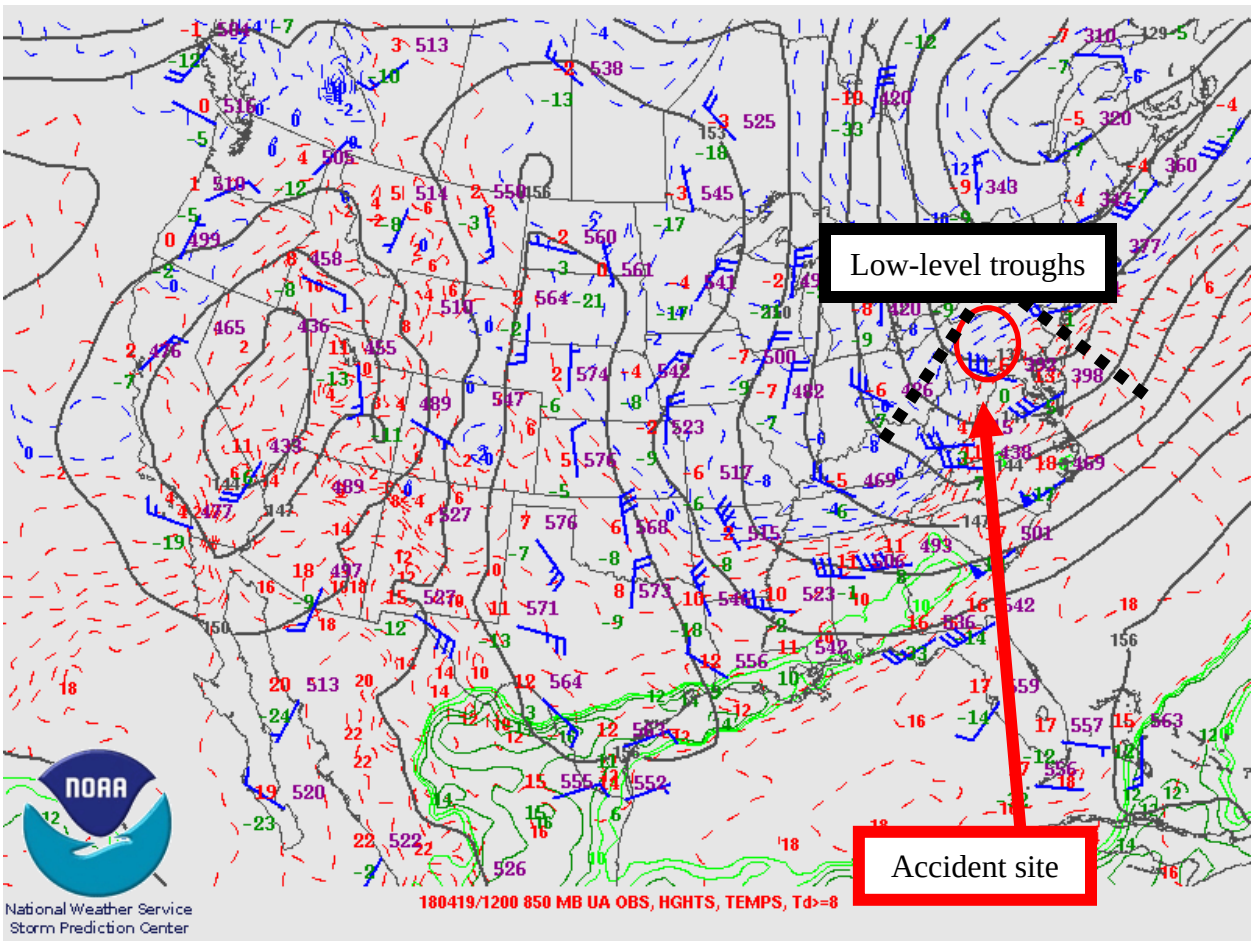



**Figure 3 – 850-hPa Constant Pressure Chart for 0800 EDT**

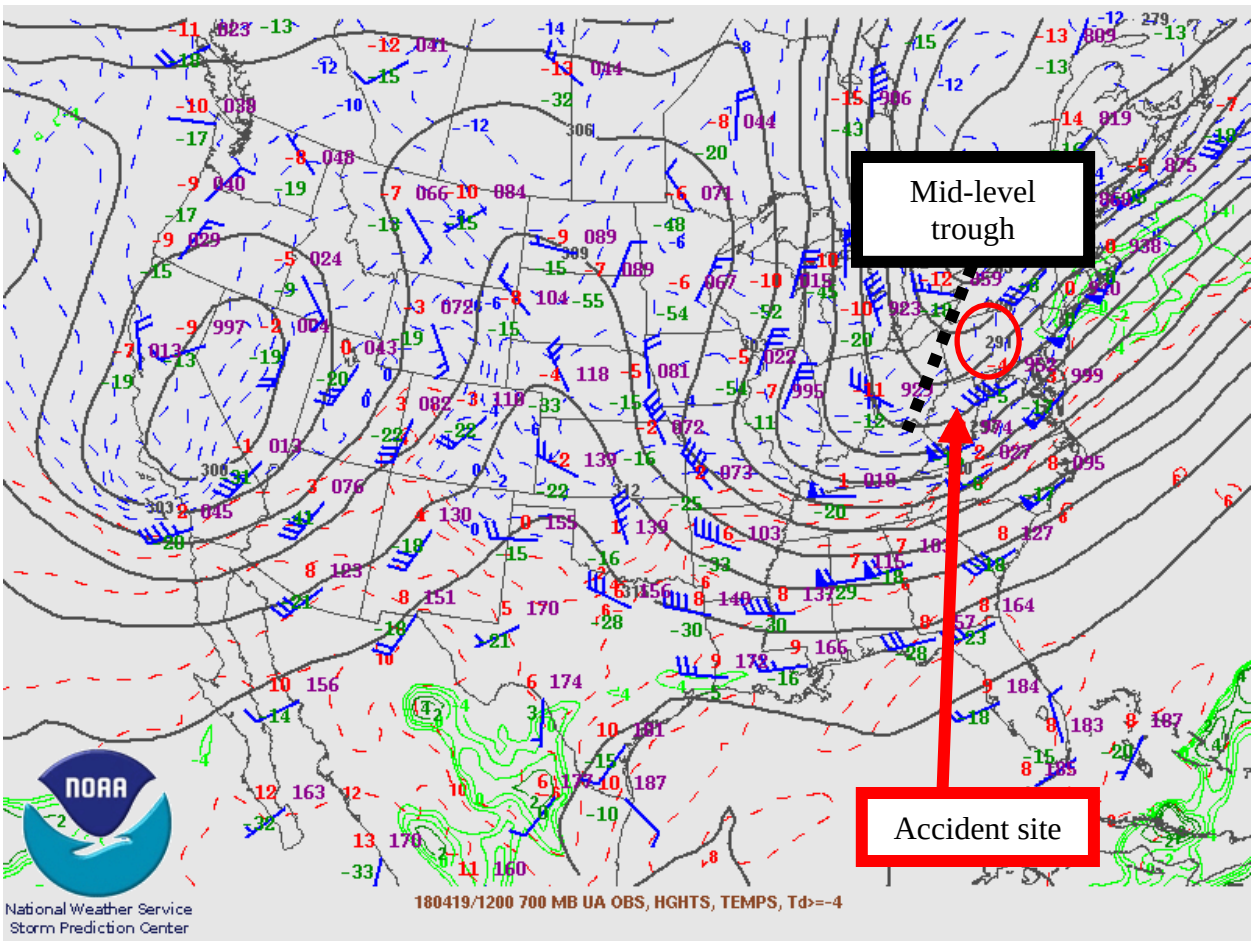



**Figure 4 – 700-hPa Constant Pressure Chart for 0800 EDT**

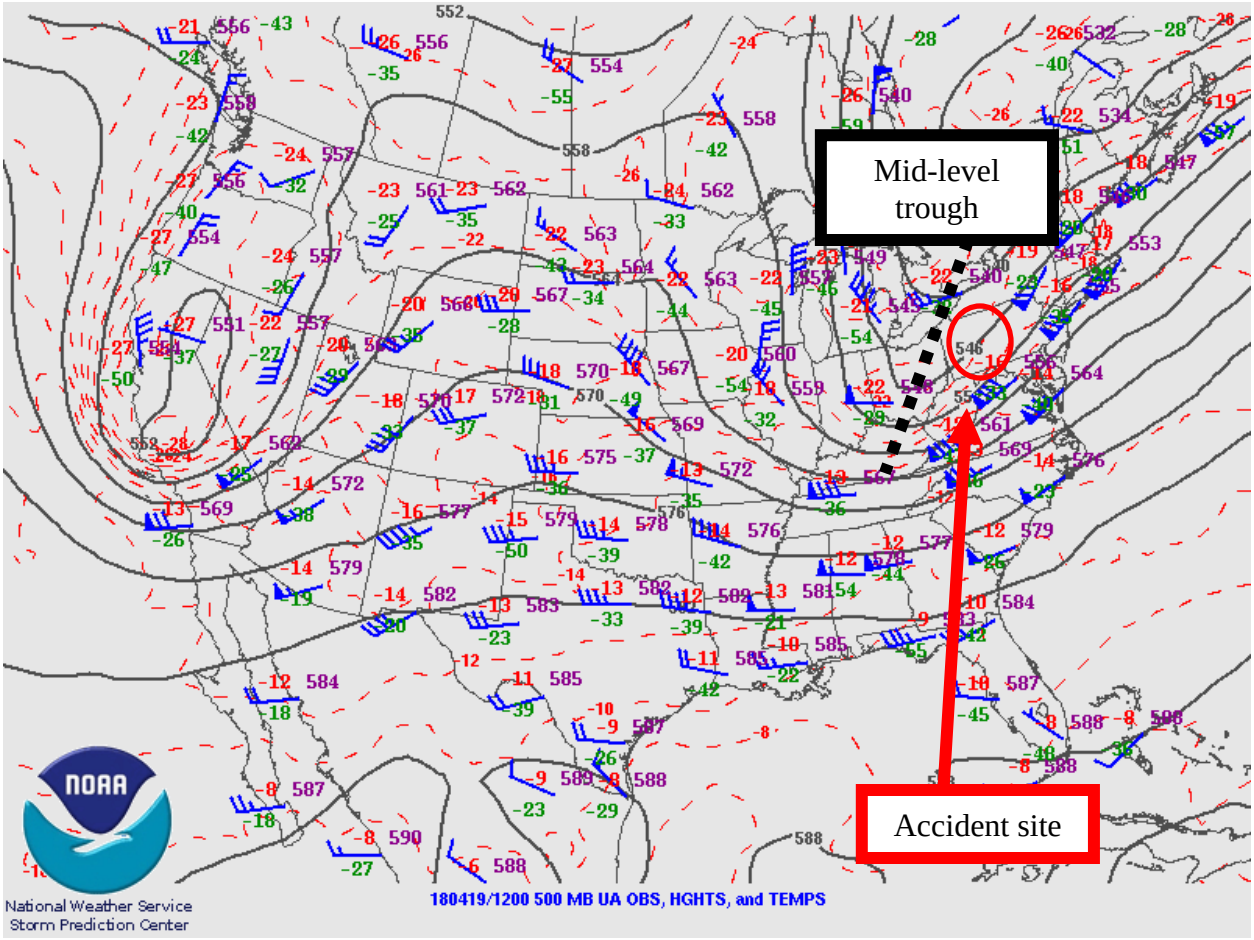



**Figure 5 – 500-hPa Constant Pressure Chart for 0800 EDT**

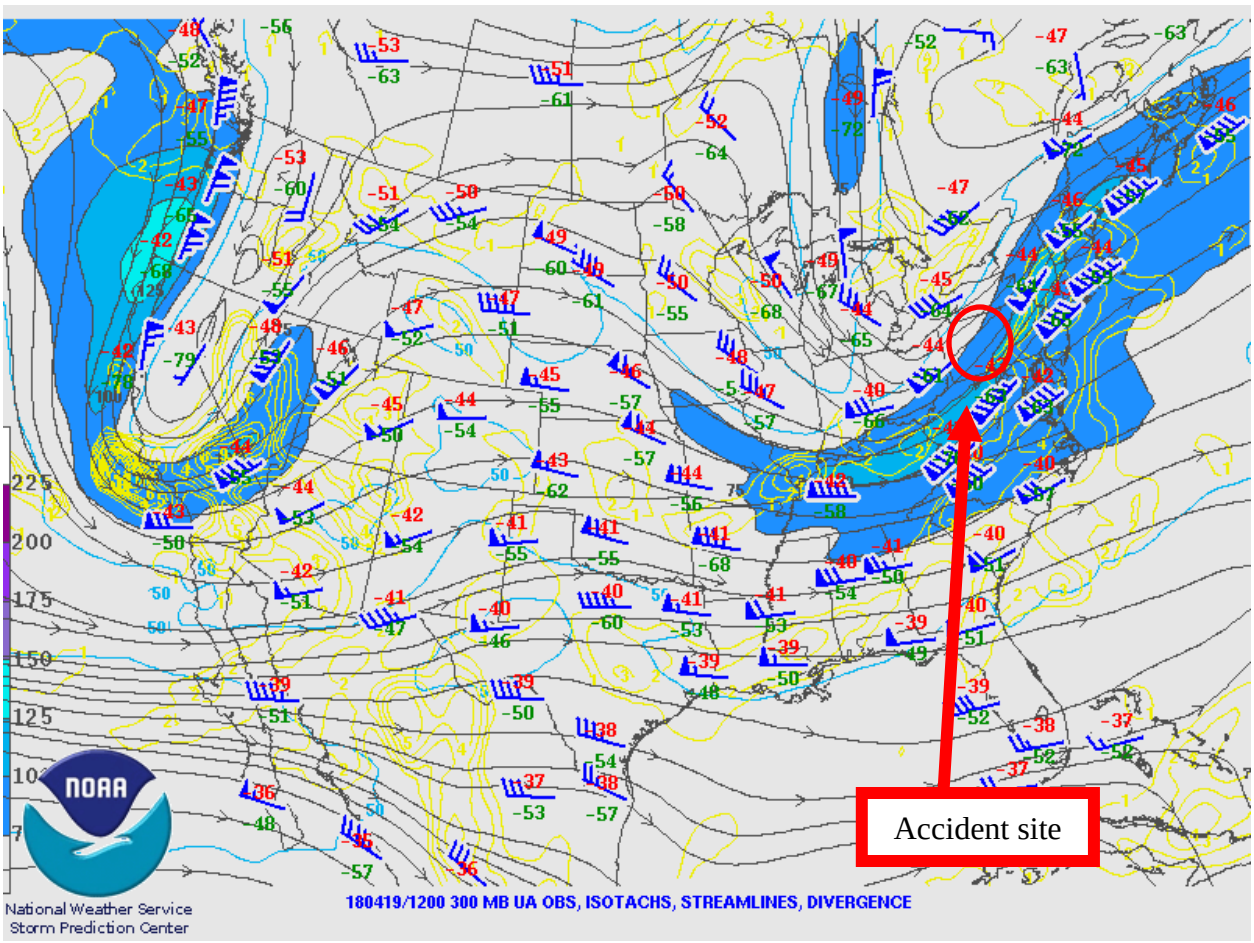



**Figure 6 – 300-hPa Constant Pressure Chart for 0800 EDT**

## 2.0 SPC Products

The NWS Storm Prediction Center (SPC) Convective Outlook expected no organized thunderstorms over the region during the period.

## 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 7 is a local sectional chart with the accident site and the closest weather reporting locations marked.


**Figure 7 – Sectional map of the accident area with the location of the accident site and surface observation sites**

Altoona-Blair County Airport (KAOO) had the closest official weather station to the accident site and was located 12 miles south of Altoona, Pennsylvania. KAOO had an Automated Surface Observing System (ASOS[3]) whose reports were not supplemented. KAOO was located 9 miles south-southwest of the accident site, at an elevation of 1,503 ft, and had a 10° westerly magnetic variation[4] (figure 7). The following observations were taken and disseminated during the times surrounding the accident:[5]

[0553 EDT] METAR KAOO 190953Z AUTO 00000KT 6SM BR OVC019 06/04 A2964 RMK AO2 SLP041 T00610044 $=

[0637 EDT] SPECI KAOO 191037Z AUTO 00000KT 5SM BR OVC013 06/04 A2966 RMK AO2 T00610044 $=

[0653 EDT] METAR KAOO 191053Z AUTO 00000KT 5SM BR OVC012 06/05 A2967 RMK AO2 SLP051 T00610050 $=

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

[4] Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from http://www.airnav.com/airport/KAOO

[5] The bold sections in this NWS product and the rest of products in this report are intended to highlight the sections that directly reference the weather conditions that effected the accident location around the accident time. The local times in section 3.0 next to the METARs are provided for quick reference between UTC and local times around the accident time.

[0753 EDT] METAR KAOO 191153Z AUTO 31003KT 2 1/2SM -RA BR OVC009 07/05 A2970 RMK AO2 RAB50 SLP059 P0000 6//// 7//// T00670050 53013 $=

[0807 EDT] SPECI KAOO 191207Z AUTO 32004KT 1 3/4SM -RA BR OVC008 07/04 A2970 RMK AO2 CIG 005V010 P0000 T00670044 $=

[0824 EDT] SPECI KAOO 191224Z AUTO 36005KT 3/4SM -RA BR BKN003 OVC007 06/04 A2970 RMK AO2 P0001 T00610044 $=

***[0826 EDT] SPECI KAOO 191226Z AUTO 36006KT 1SM -RA BR OVC005 06/04 A2970 RMK AO2 CIG 002V009 P0001 T00610044 $=***

***[0839 EDT] SPECI KAOO 191239Z AUTO 01007KT 2SM -RA BR BKN005 OVC008 06/04 A2971 RMK AO2 CIG 002V006 P0001 T00560039 $=***

**ACCIDENT TIME 0843 EDT**

***[0853 EDT] METAR KAOO 191253Z AUTO 01011KT 4SM -RA BR OVC005 06/03 A2972 RMK AO2 SLP067 P0001 T00560033 $=***

***[0930 EDT] SPECI KAOO 191330Z AUTO 32011KT 9SM -RA FEW008 BKN017 OVC026 05/02 A2975 RMK AO2 RAE1254B20 P0001 T00500022 $=***

[0953 EDT] METAR KAOO 191353Z AUTO 33012KT 10SM -RA SCT016 BKN022 OVC060 04/02 A2976 RMK AO2 RAE1254B20 SLP084 P0001 T00440017 $=

[1053 EDT] METAR KAOO 191453Z AUTO 30015G20KT 10SM BKN015 OVC023 04/01 A2981 RMK AO2 RAE44 SLP100 P0000 60002 T00440006 53036 $=

KAOO weather at 0826 EDT, automated, wind from 360° at 6 knots, 1 mile visibility, light rain and mist, overcast ceiling at 500 ft above ground level (agl), temperature of 6° Celsius (C), dew point temperature of 4° C, and an altimeter setting of 29.70 inches of mercury. Remarks: automated station with a precipitation discriminator, ceiling varying between 200 and 900 ft agl, 0.01 inches of precipitation since 0753 EDT, temperature 6.1° C, dew point temperature 4.4° C, maintenance is needed on the system.

KAOO weather at 0839 EDT, automated, wind from 010° at 7 knots, 2 miles visibility, light rain and mist, a broken ceiling at 500 ft agl, overcast skies at 800 ft agl, temperature of 6° C, dew point temperature of 4° C, and an altimeter setting of 29.71 inches of mercury. Remarks: automated station with a precipitation discriminator, ceiling varying between 200 and 600 ft agl, 0.01 inches of precipitation since 0753 EDT, temperature 5.6° C, dew point temperature 3.9° C, maintenance is needed on the system.

KAOO weather at 0853 EDT, automated, wind from 010° at 11 knots, 4 miles visibility, light rain and mist, an overcast ceiling at 500 ft agl, temperature of 6° C, dew point temperature of 3° C, and an altimeter setting of 29.72 inches of mercury. Remarks: automated station with a precipitation discriminator, sea level pressure 1006.7 hPa, 0.01 inches of precipitation since 0753 EDT, temperature 5.6° C, dew point temperature 3.9° C, maintenance is needed on the system.

KAOO weather at 0930 EDT, automated, wind from 320° at 11 knots, 9 miles visibility, light rain, few clouds at 800 ft agl, a broken ceiling at 1,700 ft agl, overcast skies at 2,600 ft agl, temperature of 5° C, dew point temperature of 2° C, and an altimeter setting of 29.75 inches of mercury. Remarks: automated station with a precipitation discriminator, rain ended at 0854 EDT, rain began at 0920 EDT, 0.01 inches of precipitation since 0853 EDT, temperature 5.0° C, dew point temperature 2.2° C, maintenance is needed on the system.

John Murtha Johnstown-Cambria County Airport (KJST) was the original diversion airport by the accident aircraft[6] and was located 3 miles northeast of Johnstown, Pennsylvania. KJST had an ASOS whose reports were not supplemented. KJST was located 29 miles west-southwest of the accident site, at an elevation of 2,284 ft, and had a 10° westerly magnetic variation[7] (figure 7). The following observations were taken and disseminated during the times surrounding the accident:

[0604 EDT] SPECI KJST 191004Z AUTO 27008KT 1/4SM FG VV002 04/03 A2964 RMK AO2 T00440033=

[0654 EDT] METAR KJST 191054Z AUTO 27009KT M1/4SM FG VV001 04/03 A2965 RMK AO2 SLP049 T00440033=

[0754 EDT] METAR KJST 191154Z AUTO 30011KT 1/4SM -RA FG VV002 03/02 A2968 RMK AO2 RAB26 SLP059 P0001 60008 70026 T00330022 10050 20033 53014=

[0805 EDT] SPECI KJST 191205Z AUTO 30013KT 1SM -RA BR VV002 03/02 A2969 RMK AO2 P0000 T00280017=

[0822 EDT] SPECI KJST 191222Z AUTO 31014KT 2 1/2SM -RA BR OVC002 02/01 A2969 RMK AO2 P0001 T00220011=

[0829 EDT] SPECI KJST 191229Z AUTO 31013KT 4SM UP BR OVC002 02/01 A2970 RMK AO2 RAE25UPB25 P0001 T00220011=

***[0838 EDT] SPECI KJST 191238Z AUTO 31012KT 4SM BR OVC003 02/01 A2971 RMK AO2 RAE25UPB25E31 PRESRR P0001 T00170006=***

***[0842 EDT] SPECI KJST 191242Z AUTO 29014KT 1 3/4SM BR OVC003 02/01 A2971 RMK AO2 RAE25UPB25E31 PRESRR P0001 T00170006=***

[6] For more information please see the Air Traffic Control (ATC) data from this accident.
[7] Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from http://www.airnav.com/airport/KJST

**ACCIDENT TIME 0843 EDT**

***[0852 EDT] SPECI KJST 191252Z AUTO 30014G19KT 1 1/2SM -SN BR OVC002 01/00 A2973 RMK AO2 RAE25UPB25E31SNB48 P0001=***

***[0854 EDT] METAR KJST 191254Z AUTO 31015G19KT 2SM -SN BR OVC002 01/00 A2973 RMK AO2 RAE25UPB25E31SNB48 SLP079 P0001 T00110000=***

[0908 EDT] SPECI KJST 191308Z AUTO 30011KT 1 3/4SM -SN BR OVC004 01/M01 A2973 RMK AO2 P0000 T00061006=

[0931 EDT] SPECI KJST 191331Z AUTO 30013KT 1/2SM SN FG OVC004 01/M01 A2974 RMK AO2 P0000 T00061011=

KJST weather at 0838 EDT, automated, wind from 310° at 12 knots, 4 miles visibility, mist, overcast ceiling at 300 ft agl, temperature of 2° C, dew point temperature of 1° C, and an altimeter setting of 29.71 inches of mercury. Remarks: automated station with a precipitation discriminator, rain ended at 0825 EDT, unknown precipitation began at 0825 and ended at 0831 EDT, pressure rising rapidly, 0.01 inches of precipitation since 0754 EDT, temperature 1.7° C, dew point temperature 0.6° C.

KJST weather at 0842 EDT, automated, wind from 290° at 14 knots, 1 and three quarter miles visibility, mist, overcast ceiling at 300 ft agl, temperature of 2° C, dew point temperature of 1° C, and an altimeter setting of 29.71 inches of mercury. Remarks: automated station with a precipitation discriminator, rain ended at 0825 EDT, unknown precipitation began at 0825 and ended at 0831 EDT, pressure rising rapidly, 0.01 inches of precipitation since 0754 EDT, temperature 1.7° C, dew point temperature 0.6° C.

KJST weather at 0852 EDT, automated, wind from 300° at 14 knots with gusts to 19 knots, 1 and a half miles visibility, light snow and mist, overcast ceiling at 200 ft agl, temperature of 1° C, dew point temperature of 0° C, and an altimeter setting of 29.73 inches of mercury. Remarks: automated station with a precipitation discriminator, rain ended at 0825 EDT, unknown precipitation began at 0825 and ended at 0831 EDT, snow began at 0848 EDT, 0.01 inches of precipitation since 0754 EDT.

KJST weather at 0854 EDT, automated, wind from 310° at 15 knots with gusts to 19 knots, 2 miles visibility, light snow and mist, overcast ceiling at 200 ft agl, temperature of 1° C, dew point temperature of 0° C, and an altimeter setting of 29.73 inches of mercury. Remarks: automated station with a precipitation discriminator, rain ended at 0825 EDT, unknown precipitation began at 0825 and ended at 0831 EDT, snow began at 0848 EDT, sea level pressure 1007.9 hPa, 0.01 inches of precipitation since 0754 EDT temperature 1.1° C, dew point temperature 0.0° C.

The observations from KAOO and KJST surrounding the accident time indicated IFR[8] to LIFR[9] conditions with light snow at KJST and light rain at KAOO, a gusty surface wind from the northwest, and temperatures just above freezing at the surface. Ceilings were as low as 200 ft agl at both KAOO and KJST at the accident time.

## 4.0 Upper Air Data

The closest upper air sounding to the accident site was from Pittsburgh, Pennsylvania, (KPIT), located 94 miles west of the accident site, with a site number 72520, and a station elevation of 1,224 ft. The 0800 EDT KPIT sounding was plotted on a standard Skew-T Log P diagram[10] with the derived stability parameters included in figure 8 from the surface to 500-hPa (or around 18,000 ft msl). This data was analyzed using the RAOB[11] software package. The sounding depicted the lifted condensation level (LCL)[12] at 1,264 ft msl (40 ft agl), the level of free convection (LFC)[13] at 1,273 ft msl (49 ft agl), and the convective condensation level (CCL)[14] at 2,370 ft msl (1,146 ft agl). The sounding had a greater than 90% relative humidity from the surface to 16,000 ft. The freezing level was located at 1,676 ft msl (452 ft agl). The precipitable water value was 0.54 inches.

[8] 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.
[9] Low Instrument Flight Rules (LIFR) – Refers to the general weather conditions pilots can expect at the surface. LIFR criteria means a ceiling below 500 ft agl and/or less than 1-mile visibility.
[10] 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.
[11] RAOB – (The complete Rawinsonde Observation program) is an interactive sounding analysis program developed by Environmental Research Services, Matamoras, Pennsylvania.
[12] LCL - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.
[13] 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.
[14] 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.

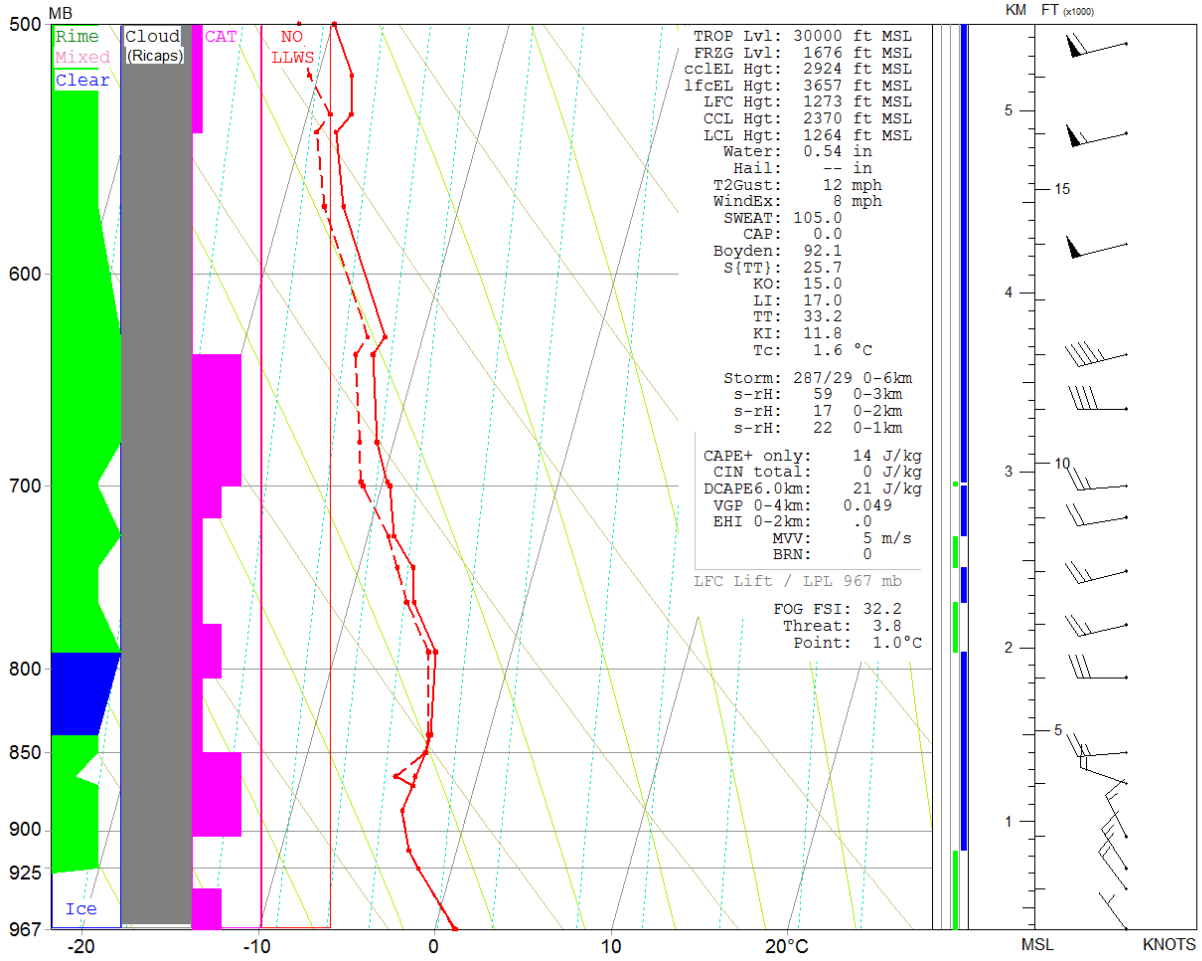



**Figure 8 – 0800 EDT KPIT sounding**

The 0800 EDT KPIT sounding indicated a conditionally unstable environment from the surface through 3,000 ft followed by a mostly stable environment from 3,000 ft through 6,500 ft. RAOB identified the possibility of clouds between the surface through 18,000 ft. Light to moderate rime and clear icing was indicated by RAOB between 2,300 ft through 18,000 ft. Icing potential will be further discussed in section 17.0.[15]

[15] S.G. Cober, G. A. Isaac, and J. W. Strapp, Characterizations of Aircraft Icing Environments that Include Supercooled Large Drops (Journal of Applied Meteorology, 2001), pp. 1984-2002.
B.C Bernstein, C.A. Wolff, and F. McDonough, An Inferred Climatology of Icing Conditions Aloft, Including Supercooled Large Drops. Part I: Canada and the Continental United States (Journal of Applied Meteorology and Climatology, 2007), pp. 1857-1878.
Williams, E.R., D.J. Smalley, M.F. Donovan, R.G. Hallowell, K.T. Hood, B.J. Bennett, R. Evaristo, A. Stepanek, T. Bals-Elsholz, J. Cobb, J. Ritzman, A. Korolev, M. Wolde, Measurements of Differential Reflectivity in Snowstorms in Warm Season Stratiform Systems (Journal of Applied Meteorology and Climatology, 2015), pp. 573-595.

The 0800 EDT KPIT sounding wind profile indicated a surface wind from 325° at 7 knots with the wind remaining northwesterly through 3,000 ft. The wind backed[16] to the west above 3,000 ft with increasing wind speeds through 18,000 ft. The wind speed was as high as 25 knots between the surface and 5,000 ft. By 18,000 ft the wind speed was 60 knots from the west-southwest. RAOB did not indicate the possibility of low-level wind shear (LLWS) between the surface and 2,000 ft. RAOB indicated a moderate probability of light to moderate clear-air turbulence in several layers between the surface and 18,000 ft. At the accident airplane's cruising altitude[17] of 6,000 ft, the sounding indicated a west wind at 31 knots with a temperature of -4º C, and with a relative humidity of 98%.

## 5.0 Satellite Data

The Geostationary Operational Environmental Satellite number 16 (GOES-16) infrared and visible 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 0600 EDT through 1100 EDT were reviewed, and the closest images to the time of the accident are documented here.

Figures 9 and 10 present the GOES-16 visible imagery at 0842 and 0846 EDT at 3X magnification with the accident site highlighted with a red square. The visible imagery indicated an extensive layer of stratiform type cloud cover over the accident site moving from west to east (attachment 1). A transverse banding[18] features were noted from central Virginia northward through northern Pennsylvania including the accident site.

Figure 11 presents the GOES-16 infrared imagery from 0846 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 (green colors; higher cloud tops) were located west of the accident site across western Pennsylvania. Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 0800 EDT KPIT sounding, the approximate cloud-top heights over the accident site were 10,400 ft at 0846 EDT (262º Kelvin). It should be noted these figures have not been corrected for any parallax error.

[16] A change in wind direction with height in a counterclockwise sense in the Northern Hemisphere
[17] For more information please see the NTSB ATC information in the docket for this accident.
[18] Transverse banding - Bands of clouds oriented perpendicular to the flow in which they are embedded.

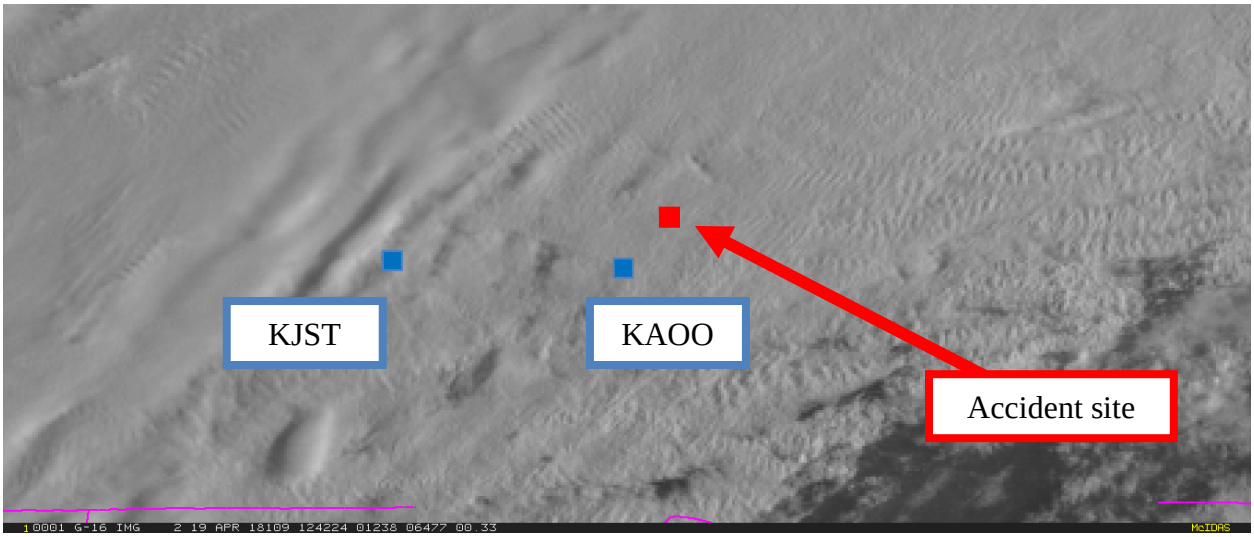



**Figure 9 – GOES-16 visible image at 0842 EDT**

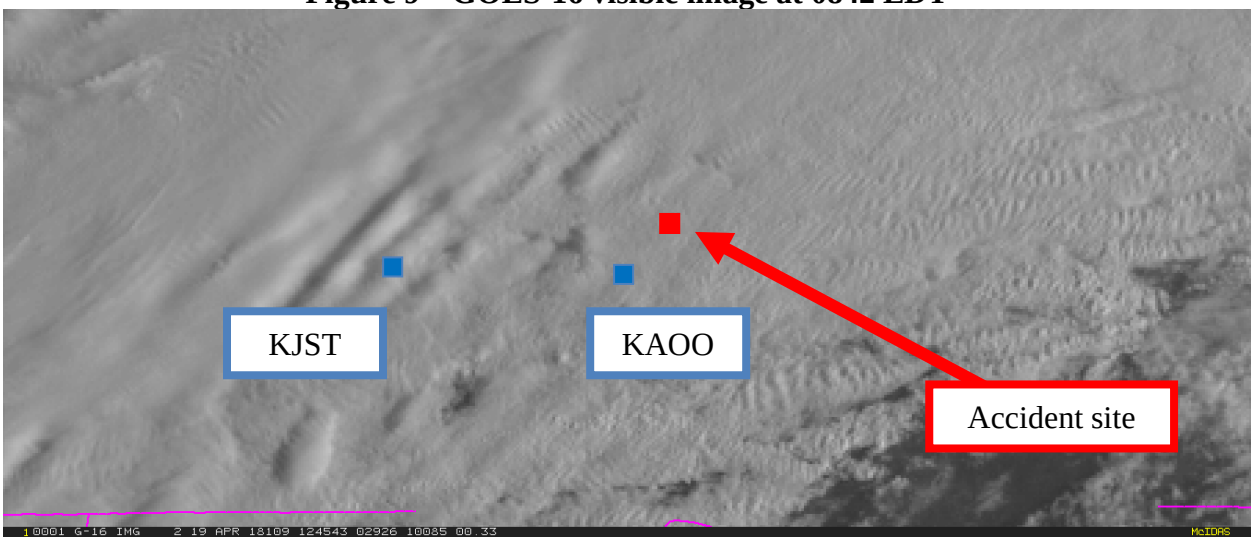



**Figure 10 – GOES-16 visible image at 0846 EDT**

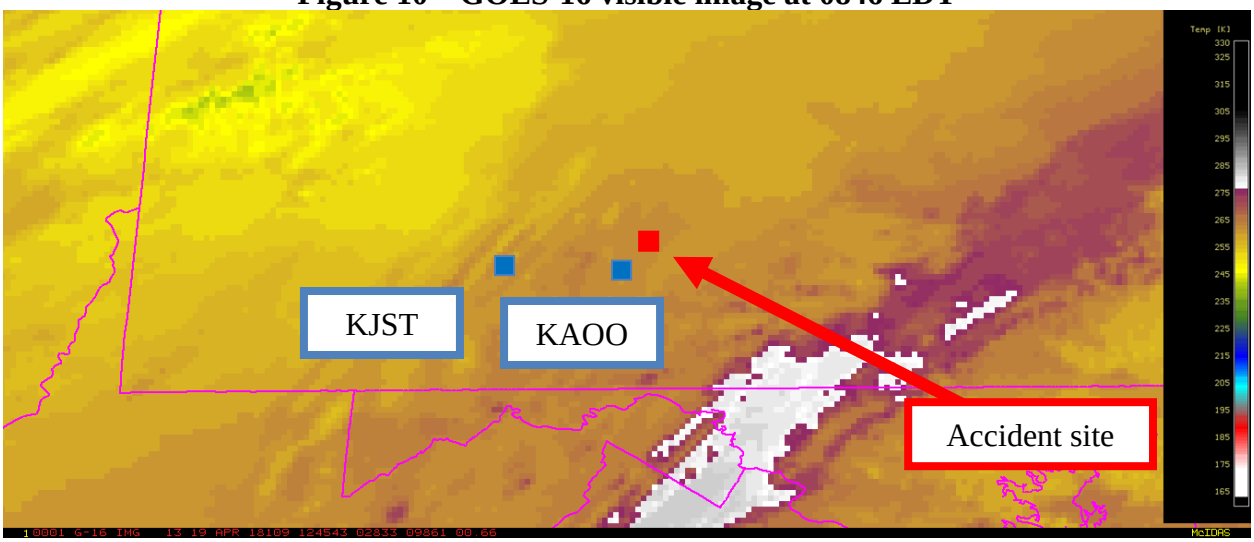



**Figure 11 – GOES-16 infrared image at 0846 EDT**

In addition, the GOES-16 Daytime Microphysics RGB imagery as described in attachment 2 were reviewed.[19] The imagery indicated aqua to blue and green RGB colors with the clouds located above the accident site around the accident time (attachment 3), which indicated thick low-level clouds, with small supercooled water droplets.

Figures 12 and 13 are the GOES-16 Icing index and icing top analysis for 0845 EDT provided by the National Aeronautics and Space Administration (NASA) Langley Research Center Climate Science Branch (LARC-E302). The imagery from 0845 EDT for the accident area suggested likely moderate or greater icing in layers between 5,000 to 10,000 ft msl and 10,000 to 15,000 ft msl.[20]

NASA LARC-E302 also created a GOES-16 infrared + visible sandwich imagery animation for the accident flight with relevant parts of the air traffic control (ATC) transcript[21] overlaid, which is included as attachment 4. This imagery indicated the accident flight was located in areas of abundant cloud cover with cloud top temperatures between -5° and -15° C throughout the flight . The accident flight turned back towards the east before reaching an area of cloud top temperatures between -15° to -25° C. For more information about infrared + visible sandwich imagery please see Setvak et al.[22]

[19] Also see: https://nasasporttraining.wordpress.com/2017/02/21/rgb-daytime-microphysics/

[20] Smith, W. L., P. Minnis, C. Fleeger, D. Spangenberg, R. Palikonda, L. Nguyen, 2012: Determining the Flight Icing Threat to Aircraft with Single-Layer Cloud Parameters Derived from Operational Satellite Data (J. Appl. Meteor. Climatol., 51), pp. 1794–1810.
Smith, W. L., Jr, 2014: 4-D cloud properties from passive satellite data and applications to resolve the flight icing threat to aircraft. PhD Dissertation, University of Wisconsin-Madison, 165 pp.

[21] For the full ATC transcript please see the NTSB docket for this accident.

[22] Setvak, M. K. M. Bedka, D. T. Lindsey, A. Sokol, Z. Charvat, J. Stastka, P. K. Wang, 2013: A-Train observations of deep convective storm tops (Atmos. Res., 123**)**, pp. 229-248.

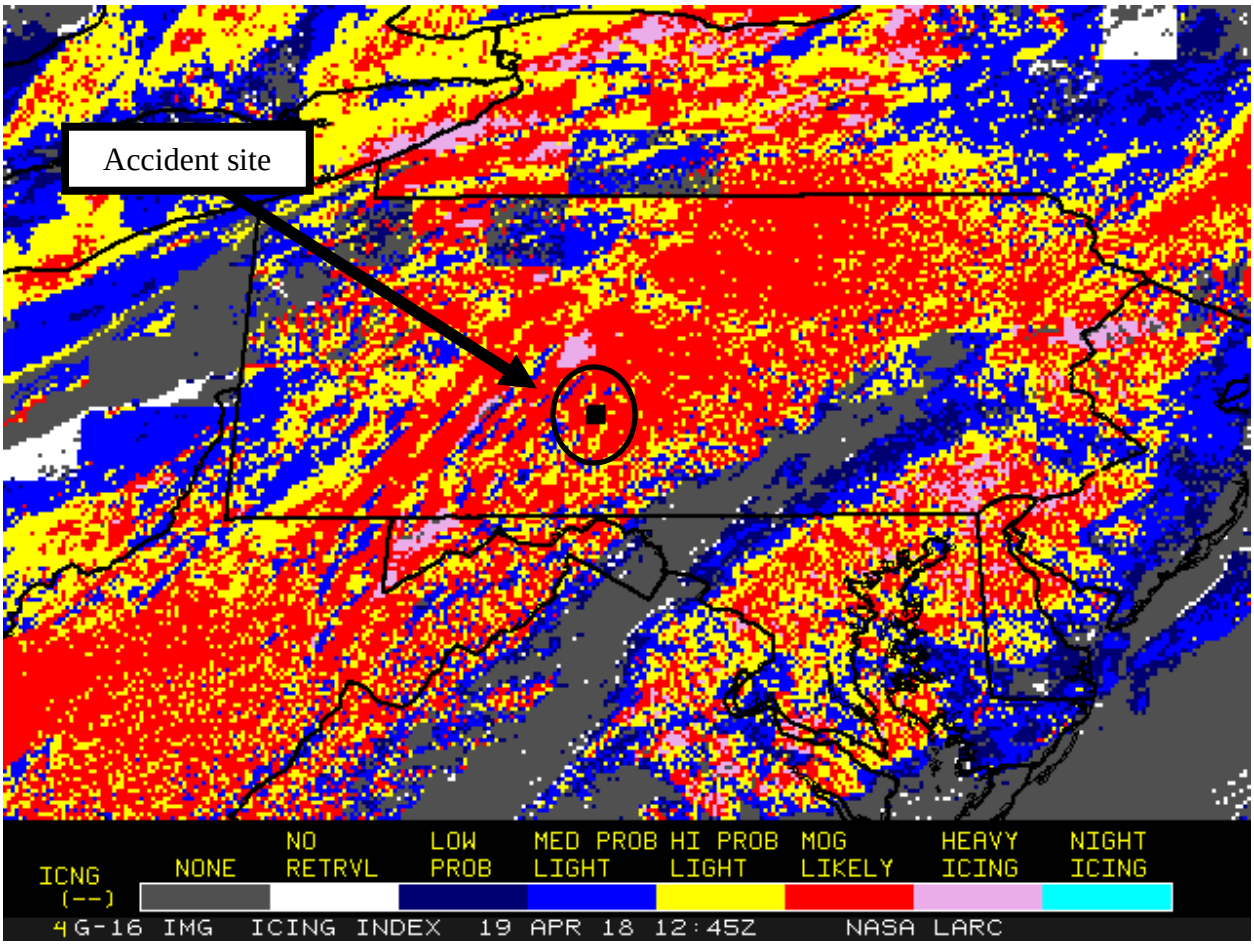



**Figure 12 – NASA LARC-E302 GOES-16 icing index image at 0845 EDT**

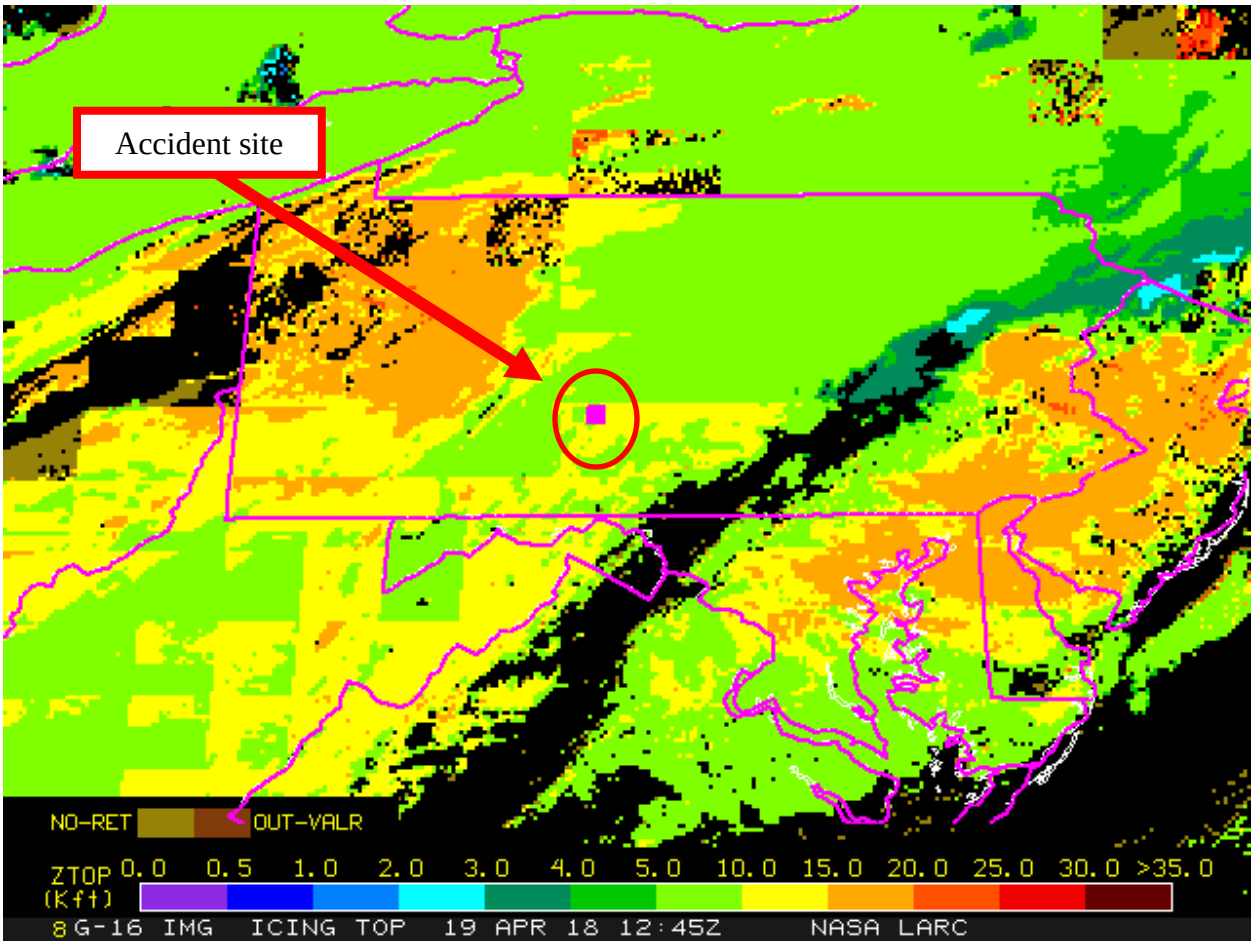



**Figure 13 – NASA LARC-E302 GOES-16 icing top image at 0845 EDT**

## 6.0 Radar Imagery Information

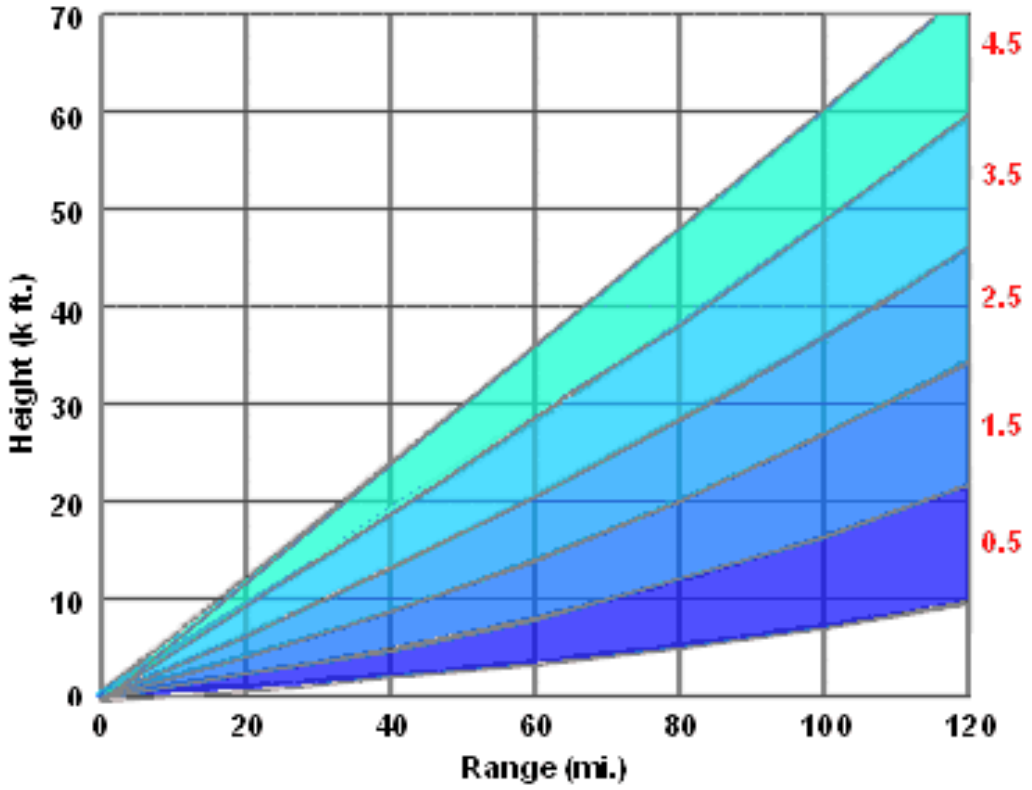
The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)[23] to the accident site was the State College, Pennsylvania, radar (KCCX), which was located 31 miles northeast of the accident site. Level II and level III archive radar data was obtained from the NCEI utilizing the NEXRAD Data Inventory Search and displayed using the NOAA's Weather and Climate Toolkit software.

### 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.

[23] 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.

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 KCCX WSR-88D radar was operating in the clear-air mode (Mode B, VCP-31). 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-31 Clear-air Mode Scan Strategy**

## 6.2 Beam Height Calculation

Assuming standard refraction[24] of the WSR-88D radar beam with the antenna elevation at 2,486 ft, and considering a beamwidth[25] 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.

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

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

| ANTENNA ELEVATION | BEAM CENTER | BEAM BASE | BEAM TOP |
|---|---|---|---|
| 0.5° | 4,830 ft | 3,300 ft | 6,360 ft |

Based on the radar height calculations, the 0.5° elevation scan depicted the conditions between 3,300 ft and 6,360 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 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 decibels (dBZ[27]), and is a general measure of echo intensity. FAA Advisory Circular AC 00-24C[28], "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.

[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] 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.

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

## 6.4 Base Reflectivity and Lightning Data

Figures 14, 15, 16, 17, and 18 present the KCCX WSR-88D base reflectivity images for the 0.5° elevation scans initiated at 0811, 0820, 0830, 0840, and 0850 EDT, respectively, with a resolution of 0.5° X 250 m. Reflectivity values between 0 and 15 dBZ were located above the accident site at the accident time. The reflectivity bands were moving from west to east in a similar direction as the cloud cover (section 5.0).

There were no lightning strikes around the accident site at the accident time.[29]

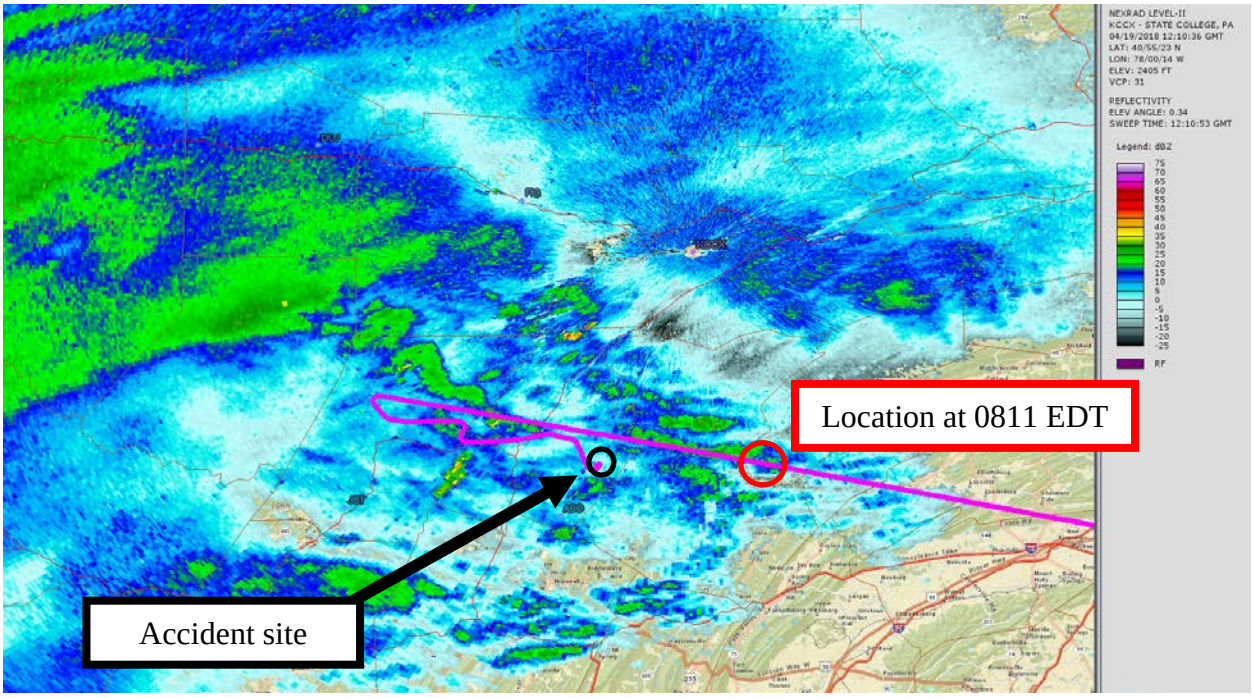



**Figure 14 – KCCX WSR-88D reflectivity for the 0.5° elevation scan initiated at 0811 EDT with the accident site marked with black circle, the accident flight track in pink**

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

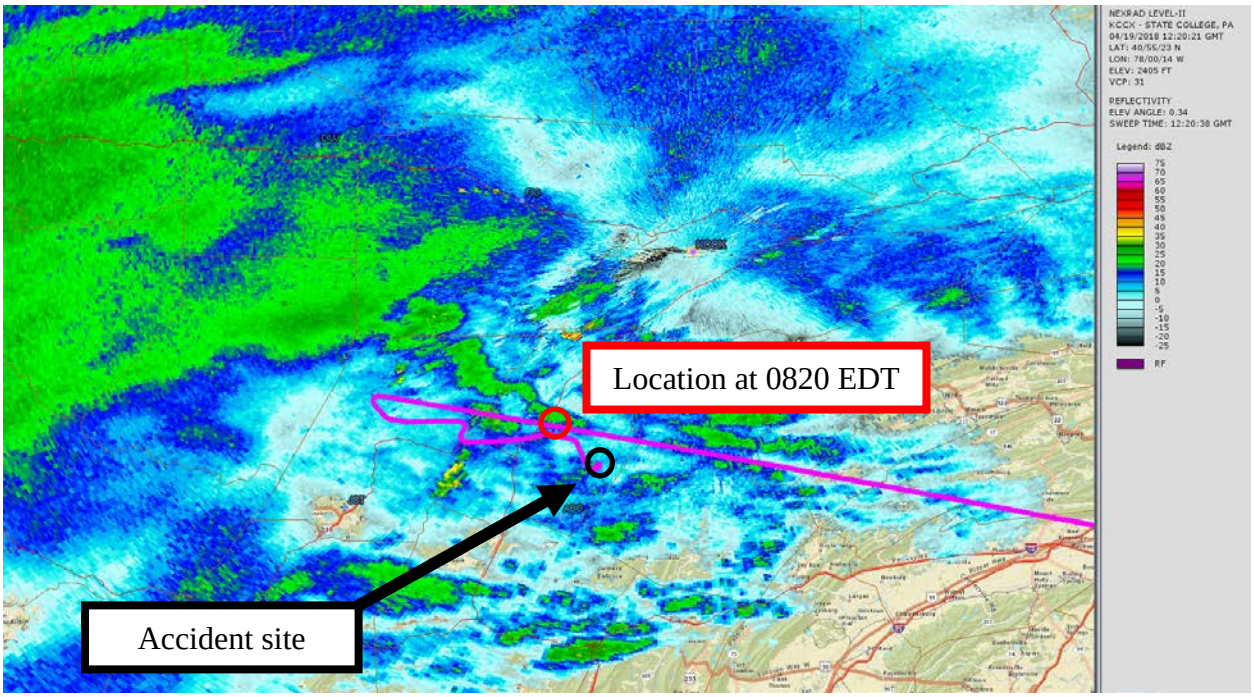



**Figure 15 – KCCX WSR-88D reflectivity for the 0.5° elevation scan initiated at 0820 EDT with the accident site marked with black circle, the accident flight track in pink**

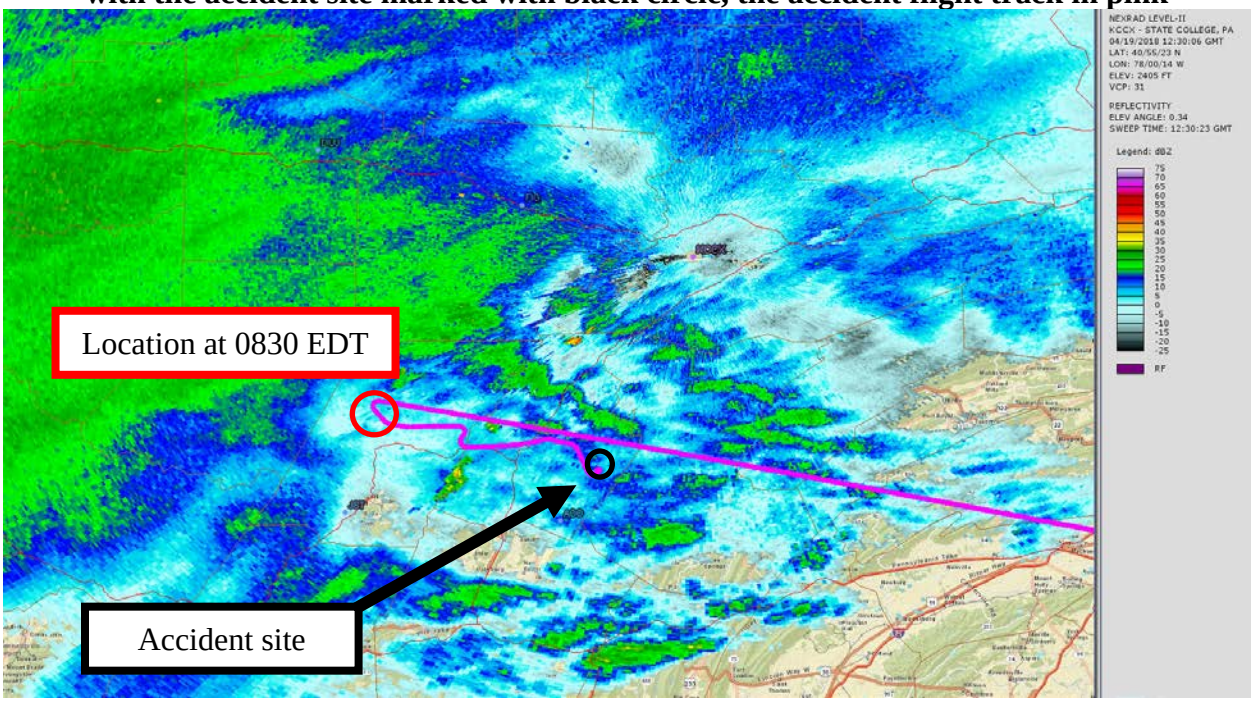



**Figure 16 – KCCX WSR-88D reflectivity for the 0.5° elevation scan initiated at 0830 EDT with the accident site marked with black circle, the accident flight track in pink**

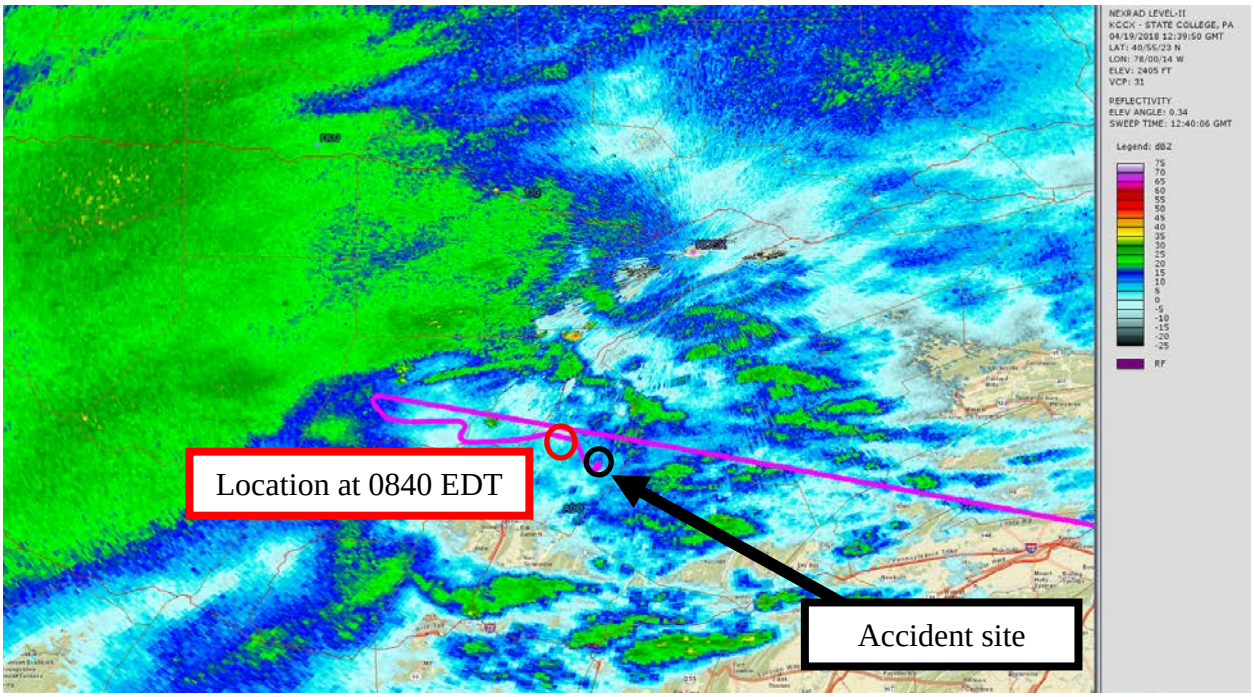



**Figure 17 – KCCX WSR-88D reflectivity for the 0.5° elevation scan initiated at 0840 EDT with the accident site marked with black circle, the accident flight track in pink**

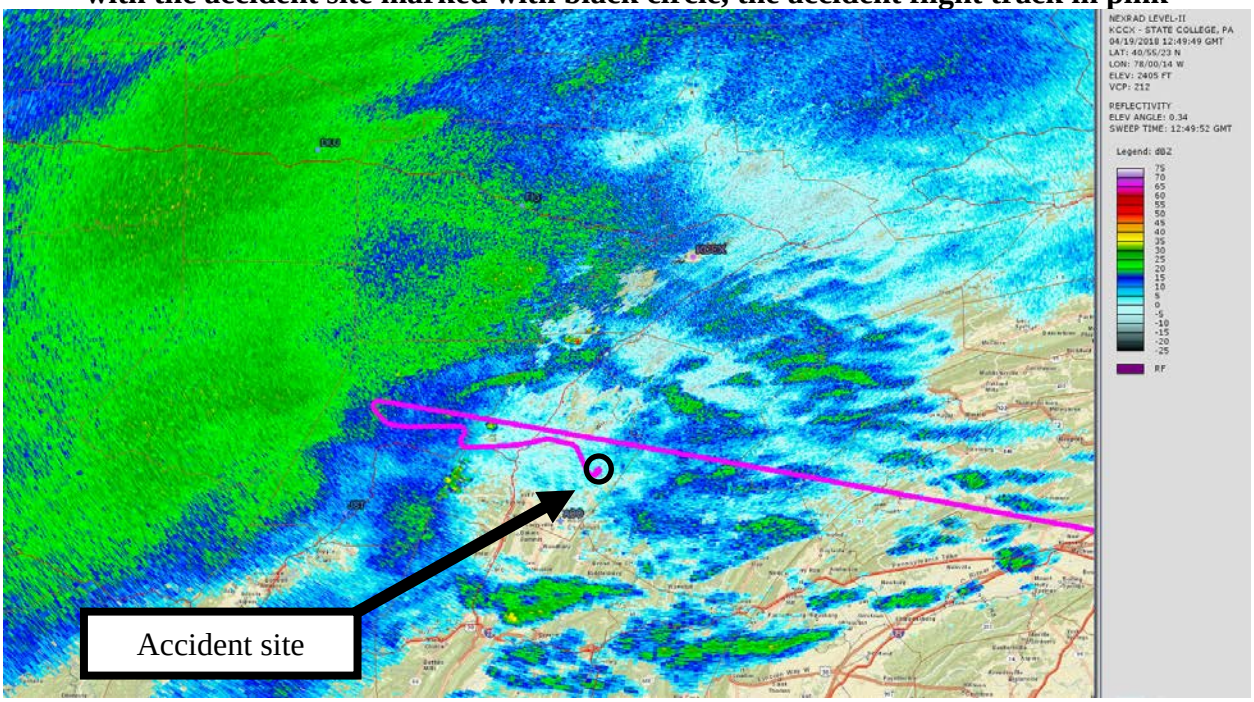



**Figure 18 – KCCX WSR-88D reflectivity for the 0.5° elevation scan initiated at 0850 EDT with the accident site marked with black circle, the accident flight track in pink**

## 6.5 Dual-Pol Products[30]

The following additional WSR-88D Dual-Polarization Products were utilized in this investigation.

Differential Reflectivity (Zdr) is the logarithm ratio of the horizontal power return to the vertical power return. Positive values of Zdr indicate that there is more horizontal power return than vertical power return.[31] A negative value of Zdr indicates that there is more vertical power return than horizontal power return indicating that the dominant hydrometeors are larger in the vertical than in the horizontal.[32] Near zero values of Zdr indicate that both the horizontal and vertical power return from within the volume scanned are of similar values, meaning the dominant hydrometeors are similar in size in both the vertical and horizontal.[33]

Correlation Coefficient (CC) is a measure of how similar the horizontal and vertical returned pulse characteristics are among all pulses in the sampled WSR-88D volume. CC provides information about the diversity of hydrometeors within the volume and the values range from 0 to 1.[34] Meteorological echoes tend to have CC values greater than 0.80, with values greater than 0.96 indicating that the meteorological targets within the volume are all very similar in size, shape, type (liquid versus solid), and orientation. CC values between 0.96 and 0.80 indicate that the meteorological targets within the volume have a higher diversity of sizes, shapes, types, and orientations as the CC trends lower. If hail is located within the volume scanned the CC values are typically between 0.80 and 0.96. Non-meteorological echoes have CC values less than 0.80 and these non-meteorological echoes can include but are not limited to bugs, chaff, smoke, and birds.

Specific Differential Phase (KDP) is a measure of the range derivative of the differential phase shift between the horizontal and vertical pulses phases. KDP has possible range values between -2 to 10 in degrees per kilometer. When a radar pulse is sent out and hits meteorological and non-meteorological targets alike, the radar pulse will have a phase shift between the horizontal and vertical pulses. Once we know the KDP value with meteorological targets, along with the other dual-pol parameters, one can tell areas of heavy rain, hail, and different characteristics in snow and ice crystals. KDP values that are large and positive often indicate areas of heavy rain. Areas with hail or snow often have KDP values much closer to 0. For non-meteorological targets, the KDP values are very noisy and difficult to interpret. In fact, for CC values less than 0.90 the KDP is not computed.

[30] Definitions for Zdr, CC, KDP, and HC adapted from training material from the NWS WDTD.
[31] A positive Zdr means that the dominant hydrometeors within the volume are larger in the horizontal than vertical (i.e. rain drops).
[32] A negative Zdr correlates to vertically oriented hydrometeors, i.e. vertically oriented crystals or conical graupel.
[33] A near zero Zdr is often an indication of hail or spherical rain drops.
[34] CC values greater than 1 indicate an untrustworthy signal due to low signal-to-noise ratio in areas of weak reflectivity.

Hydrometeor Classification (HC) is a product produced by the hydrometeor classification algorithm and the HC attempts to discriminate between 10 classes of radar echoes at every 250 m range bin. HC ingests reflectivity, Zdr, CC, Kdp, and velocity, along with radially averaged and smoothed fields of reflectivity and differential phase. HC then uses the height of the melting layer along with the previous data and assigns a radar class to each bin with a weighted value. The HC then applies a set of hard thresholds to reduce the number of clearly wrong class designations, and given the weight and likelihood of each of the 10 classes at each bin, the HC assigns the radar classification with the highest likelihood value to that particular bin.

### 6.6 Dual-Pol Imagery

Figures 19, 20, 21, and 22 present the level III KCCX WSR-88D base reflectivity, Zdr, and CC values for the 0.5° elevation scans initiated at 0811, 0820, 0830, and 0840 EDT with a resolution of 1° X 1 km.

Figures 19 and 20 depicted very light echoes in the base reflectivity at the aircraft location at 0811 and 0820 EDT, and along flight path in between, with 5 to 25 dBZ values. The Zdr values were between 0 and 1 dB, and CC values ranged between 0.97 and 1.00. These values of dual-pol data at the aircraft location and along the flight path indicated small hydrometeor sizes, and/or a small amount of hydrometeors in the beam, hydrometeors that were more horizontally shaped as they fell than spherical, and the majority of the hydrometeors in the scan near the aircraft locations at 0811 and 0820 EDT had similar characteristics.

Figure 21 depicted very light echoes at the aircraft location at 0830 EDT, and along flight path in between, with 0 to 10 dBZ values, the Zdr values were between 0 and 1.5 dB, and CC values ranged between 0.88 and 0.99. These values of dual-pol data at the aircraft location and along the flight path indicated very small hydrometeor sizes, and/or a very small amount of hydrometeors in the beam, hydrometeors that were more horizontally shaped as they fell than spherical, and the majority of the hydrometeors in the scan near the aircraft location at 0830 EDT had different characteristics.

Figure 22 depicted light echoes at the aircraft location at 0840 EDT, and along flight path in between, with 0 to 15 dBZ values, the Zdr values were between -0.5 and 0.5 dB, and CC values ranged between 0.89 and 0.99. The values of dual-pol data at the aircraft location at 0840 EDT and along the flight path indicated very small hydrometeor sizes, and/or a very small amount of hydrometeors in the beam, hydrometeors that were spherically shaped as they fell, and the majority the hydrometeors in the scan near the aircraft location at 0840 EDT had similar characteristics.

While the dBZ values remained very light to light and CC values were consistently between 0.94 and 0.99 for the majority of the accident flight track, the Zdr values did range between more spherical shaped after 0830 EDT and more horizontally shaped between 0811 and 0830 EDT. With the higher Zdr values, the accident aircraft would have encountered hydrometeors having a larger surface area in the horizontal dimension rather than the vertical dimension, meaning the hydrometeors were shaped more like pancakes, rather than spherical or tear dropped shaped as the hydrometeors fell.[35]

[35] Ikeda, Kyoko, Roy M. Rasmussen, Edward Brandes, and Frank McDonough, 2009: Freezing Drizzle Detection with WSR-88D Radars (Journal of Applied Meteorology and Climatology, 48), pp. 41-60.

Ikeda, Alexander, Heather Reeves, Terry Schuur, Matthew Kumjian, and Dusan Zrnic, 2011: Investigation of Polarmetric Radar Signatures in Winter Storms and their Relation to Aircraft Icing and Freezing Rain. 35th Conference on Radar Meteorology. Pittsburg, PA, Amer. Meteor. Soc., P13.197.

Williams, E.R., D.J. Smalley, M.F. Donovan, R.G. Hallowell, K.T. Hood, B.J. Bennett, R. Evaristo, A. Stepanek, T. Bals-Elsholz, J. Cobb, J. Ritzman, A. Korolev, M. Wolde, Measurements of Differential Reflectivity in Snowstorms in Warm Season Stratiform Systems (Journal of Applied Meteorology and Climatology, 54), pp. 573-595.

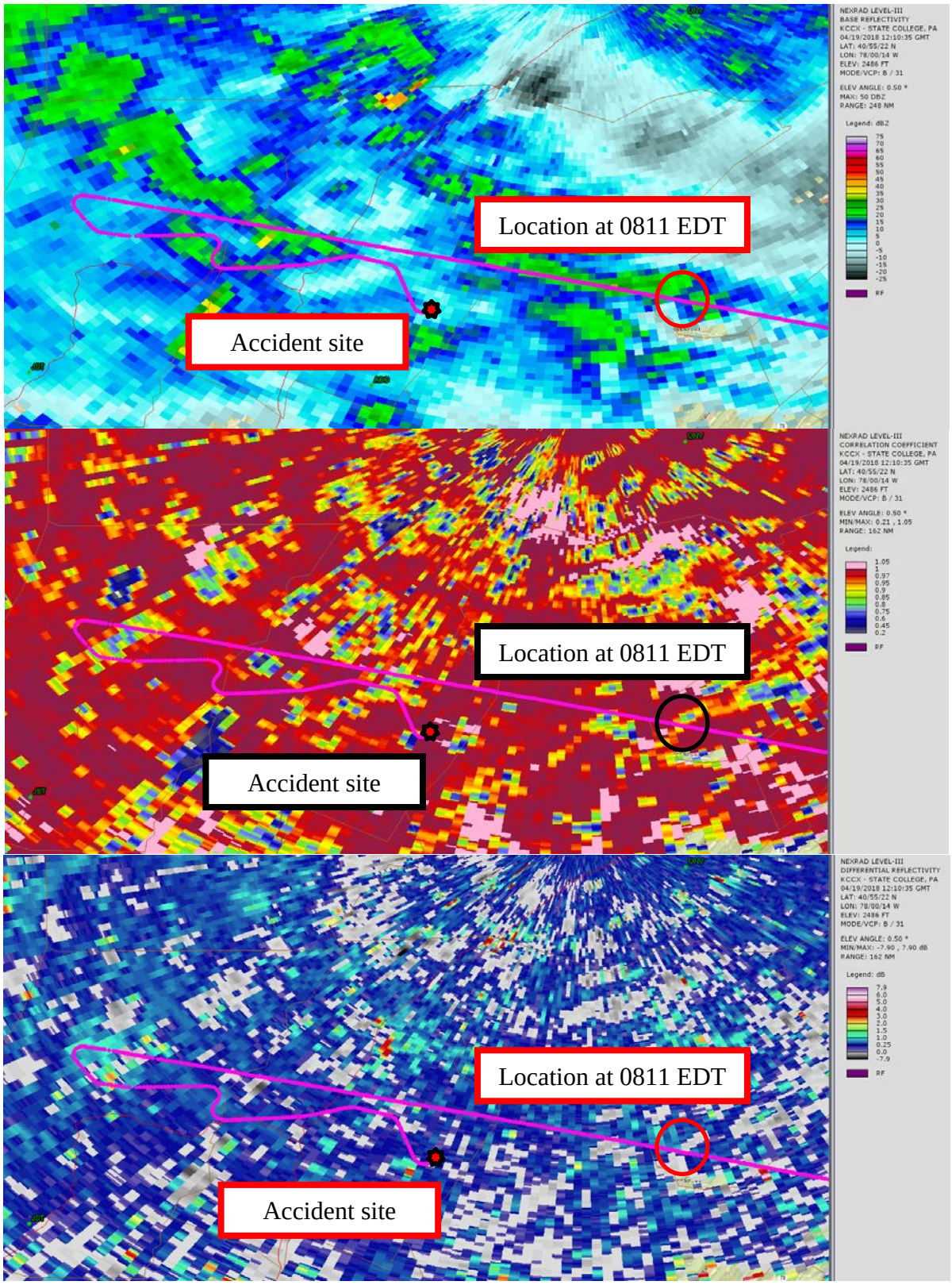



**Figure 19 – KCCX WSR-88D 0.5° elevation scan for 0811 EDT (a) base reflectivity, (b) CC, and (c) Zdr elevation scan with the accident site marked with black circle, the accident flight track in pink**

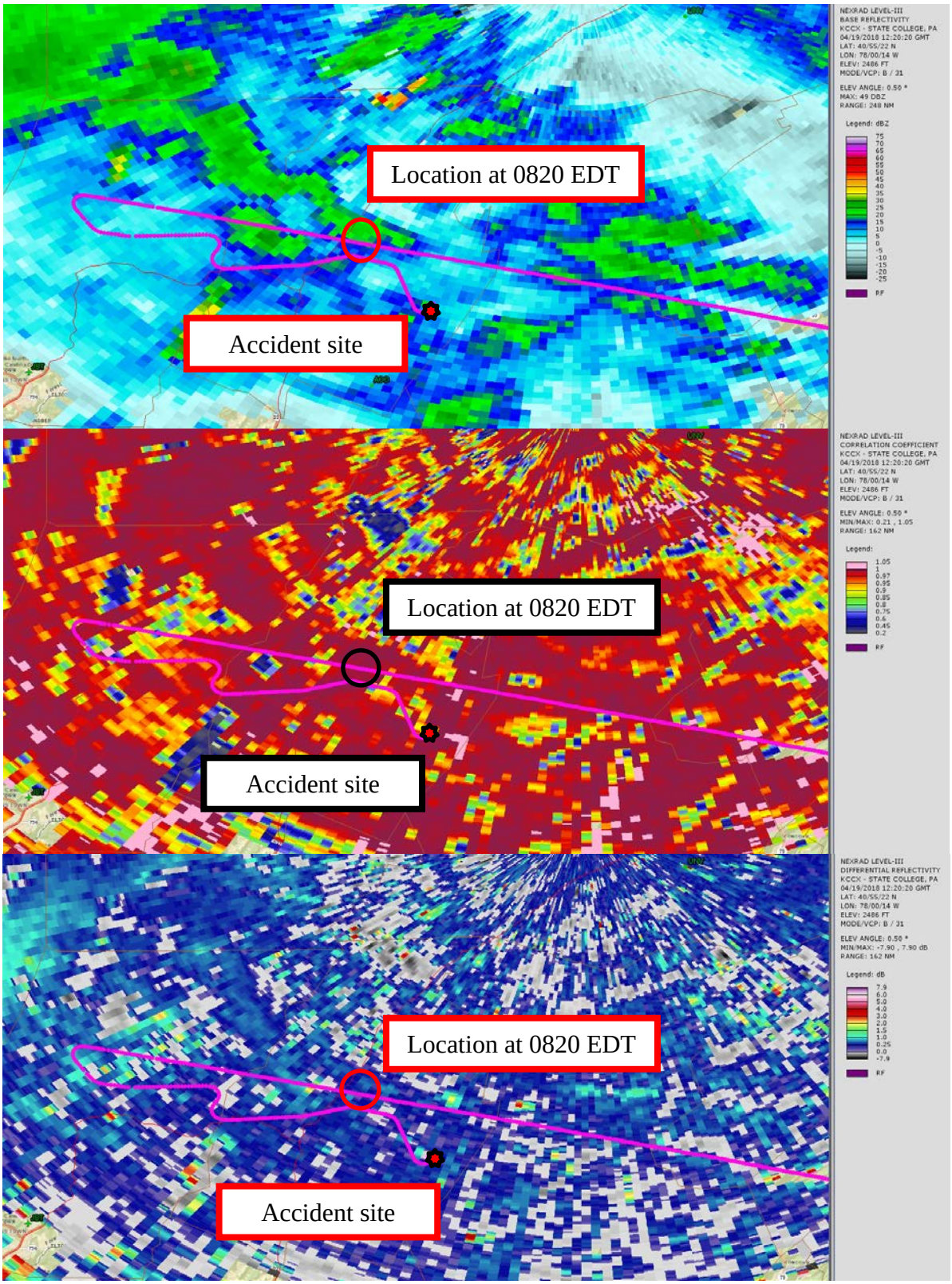



**Figure 20 – KCCX WSR-88D 0.5° elevation scan for 0820 EDT (a) base reflectivity, (b) CC, and (c) Zdr elevation scan with the accident site marked with black circle, the accident flight track in pink**

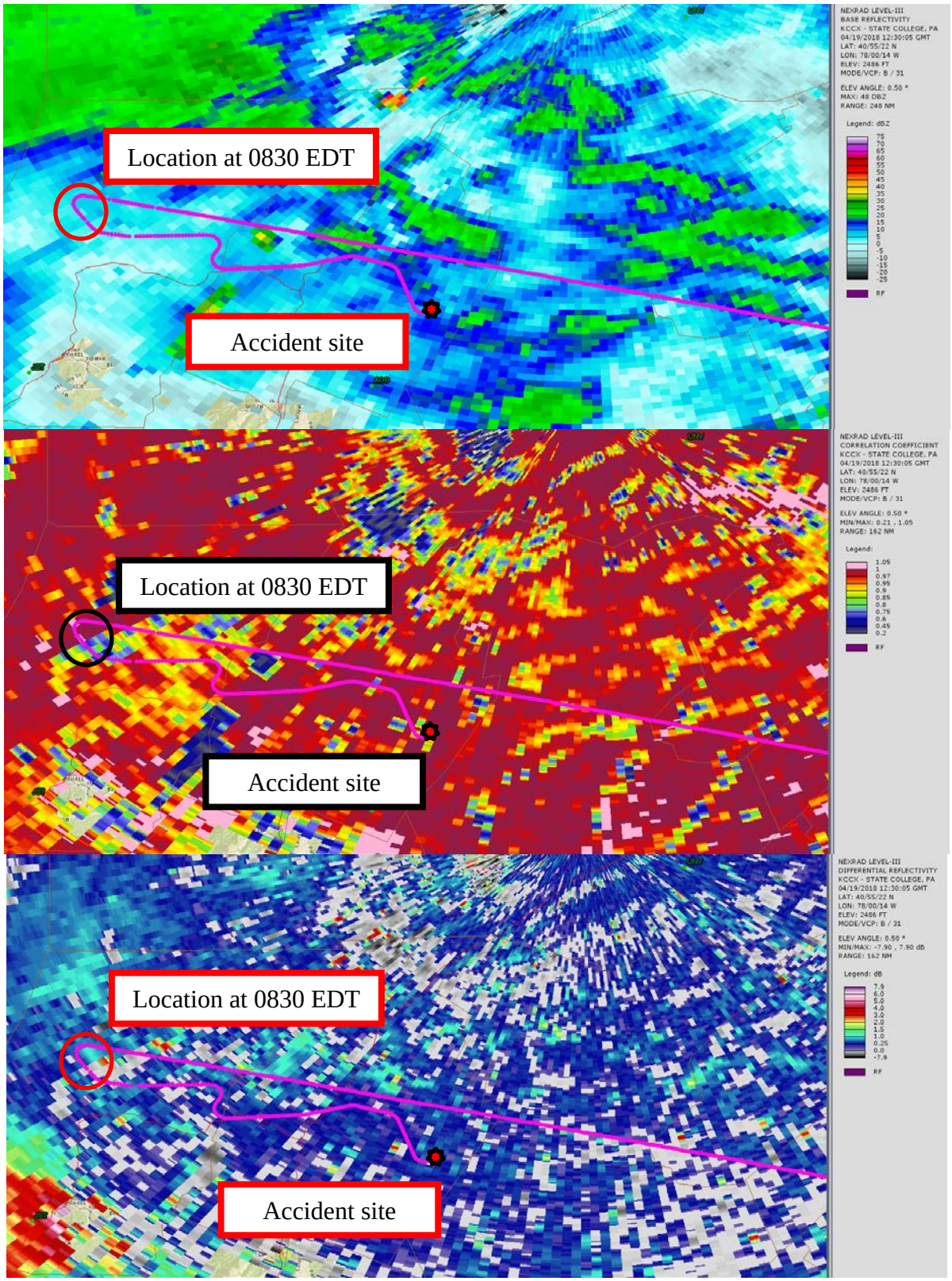



**Figure 21 – KCCX WSR-88D 0.5° elevation scan for 0830 EDT (a) base reflectivity, (b) CC, and (c) Zdr elevation scan with the accident site marked with black circle, the accident flight track in pink**

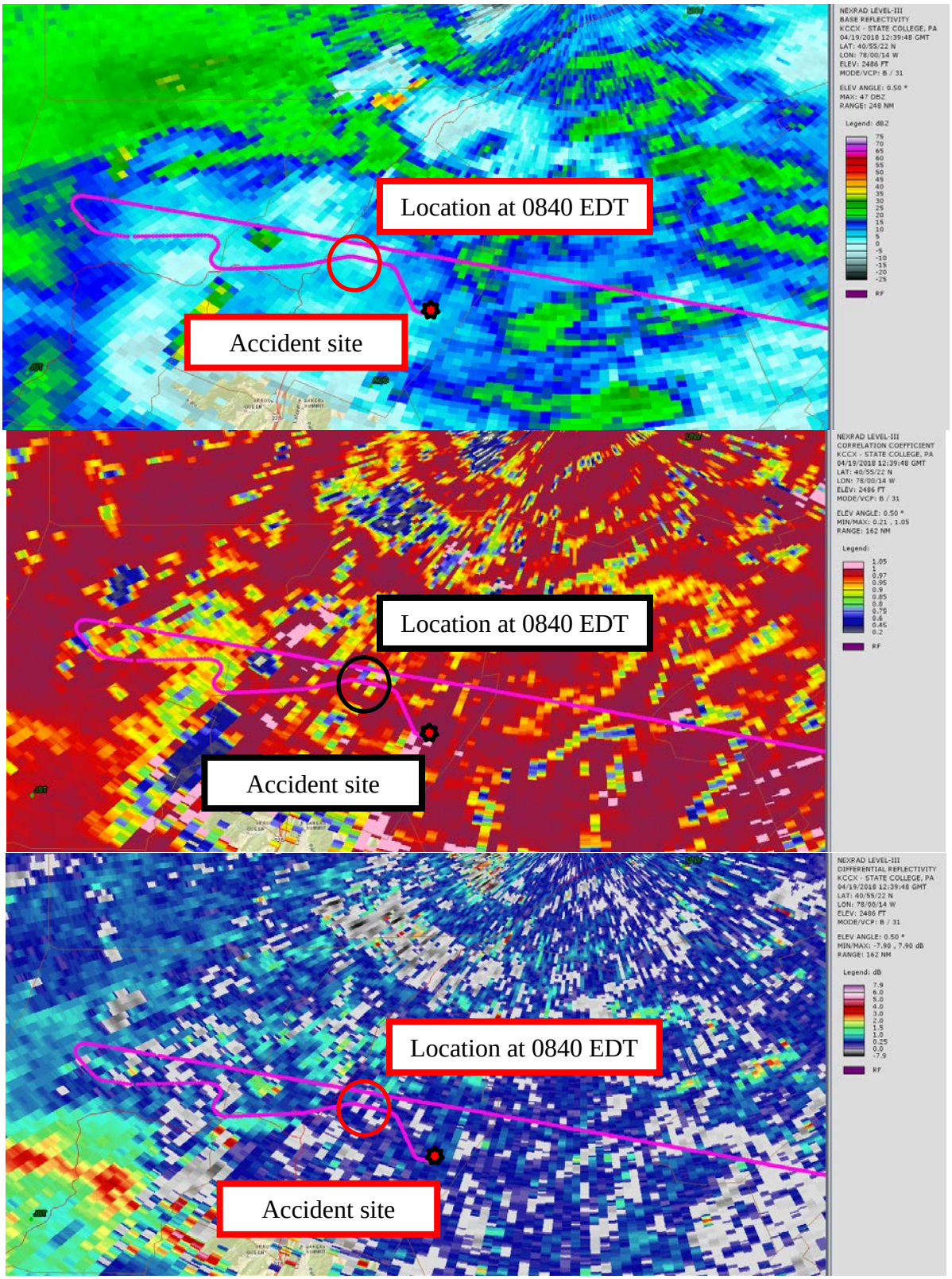



**Figure 22 – KCCX WSR-88D 0.5° elevation scan for 0840 EDT (a) base reflectivity, (b) CC, and (c) Zdr elevation scan with the accident site marked with black circle, the accident flight track in pink**

## 7.0 Pilot Reports[36]

All pilot reports (PIREPs) within 100 miles of the accident site from about two hours prior to the accident time to about two hours after the accident time for below FL200[37] are provided below:

JST UA /OV 35 NW JST/TM 1104/FL070/TP C208/TA M02/IC MOD MIXED

PIT UA /OV MMJ090015/TM 1107/FL065/TP C208/TA M02/IC MOD MX 065-080

JST UA /OV JST315043/TM 1108/FL050/TP C208/TA M02/IC LGT RIME

DMW UA /OV EMI015035/TM 1111/FL140/TP B738/TA UNKN/IC MOD RIME

UNV UA /OV KUNV/TM 1115/FL017/TP C208/SK BKN017/RM DURD RY6

IDI UA /OV MMJ-ETG/TM 1147/FL090/TP C208/TA M05/IC MOD MX 090-042/RM DURD

IAD UA /OV 40 EAST OF HGR/TM 1203/FL090/TP B190/TA -4/IC MODERATE RIME

FIG UA /OV ETG225020/TM 1234/FL042/TP C208/TA UNKN/IC LGT MX

IPT UA /OV ETG290005/TM 1243/FL120/TP MU2/IC MOD

PSB UA /OV PSB150010/TM 1249/FL090/TP C208/TA M07/IC MOD MX

DUJ UA /OV CIP180010/TM 1249/FL165/TP BE40/TA M18/IC LGT RIME 165-042/RM DURD

MDT UA /OV HAR225010/TM 1253/FL095/TP FA20/TA M08/IC LGT RIME

MDT UA /OV HAR315025/TM 1255/FL070/TP C208/TA M07/IC MOD MX

UNV UA /OV UNV/TM 1316/FL040/TP E145/TA M04/IC LGT MX/RM LIGHT MIXED ICE ON APPROACH

IAD UA /OV AML015035/TM 1430/FL080/TP CRJ2/TA M05/IC MOD RIME/RM IN DESCENT FROM 080-055

AGC UA /OV 1/2 MILE FINAL 28/TM 1442/FL002/TP C525/RM +/- 10 LAST 200 FT

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

Routine pilot report (UA) KJST; Over 35 miles northwest of KJST; Time – 0704 EDT (1104Z); Altitude – 7,000 ft; Type aircraft – Cessna 208; Temperature – -2° C; Icing – Moderate mixed.

[36] Only pilot reports with the World Meteorological Organization header UBPA**, UBVA**, UBMD**, and UBWV** identifier were considered.

[37] 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.

Routine pilot report (UA) Pittsburgh International Airport, Pennsylvania (PIT); Over 15 miles from Montour DME, Pennsylvania, (MMJ) VORTAC on the 090° radial; Time – 0707 EDT (1107Z); Altitude – 6,500 ft; Type aircraft – Cessna 208; Temperature – -2° C; Icing – Moderate mixed between 6,500 and 8,000 ft.

Routine pilot report (UA) KJST; Over 43 miles from KJST on the 315° radial; Time – 0708 EDT (1108Z); Altitude – 5,000 ft; Type aircraft – Cessna 208; Temperature – -2° C; Icing – Light rime.

Routine pilot report (UA) Carroll County Regional Airport, Maryland (DMW); Over 35 miles from Westminster, Maryland, (EMI) VORTAC on the 015° radial; Time – 0711 EDT (1111Z); Altitude – 14,000 ft; Type aircraft – Boeing B737-800; Temperature – Unknown; Icing – Moderate rime.

Routine pilot report (UA) University Park Airport, Pennsylvania (UNV); Over UNV; Time – 0715 EDT (1115Z); Altitude – 1,700 ft; Type aircraft – Cessna 208; Sky – Broken skies at 1,700 ft; Remarks – During descent to runway 6.

Routine pilot report (UA) Indiana County Airport, Pennsylvania (IDI); Over between MMJ and Keating, Pennsylvania, (ETG) VORTAC; Time – 0747 EDT (1147Z); Altitude – 9,000 ft; Type aircraft – Cessna 208; Temperature – -5° C; Icing – Moderate mixed between 9,000 ft and 4,200 ft; Remarks – During descent.

Routine pilot report (UA) Washington Dulles International Airport, Virginia (IAD); Over 40 miles east of Hagerstown, Maryland, (HRG) VORTAC; Time – 0803 EDT (1203Z); Altitude – 9,000 ft; Type aircraft – Beechcraft 1900; Temperature – -4° C; Icing – Moderate rime.

Routine pilot report (UA) Clearfield-Lawrence Airport, Pennsylvania (FIG); Over 20 miles from ETG on the 225° radial; Time – 0834 EDT (1234Z); Altitude – 4,200 ft; Type aircraft – Cessna 208; Temperature – Unknown; Icing – Light mixed.

Routine pilot report (UA) Williamsport Regional Airport, Pennsylvania (IPT); Over 5 miles from ETG on the 290° radial; Time – 0843 EDT (1243Z); Altitude – 12,000 ft; Type aircraft – Mitsubishi MU-2; Icing – Moderate.

Routine pilot report (UA) Mid-State Airport, Pennsylvania (PSB); Over 10 miles from PSB on the 150° radial; Time – 0849 EDT (1249Z); Altitude – 9,000 ft; Type aircraft – Cessna 208; Temperature – -7° C; Icing – Moderate mixed.

Routine pilot report (UA) Dubois Regional Airport, Pennsylvania (DUJ); Over 10 miles from Clarion, Pennsylvania, (CIP) on the 180° radial; Time – 0849 EDT (1249Z); Altitude – 16,500 ft; Type aircraft – Beech 400 Beechjet; Temperature – -18° C; Icing – Light rime between 16,500 and 4,200 ft; Remarks – During descent.

Routine pilot report (UA) Harrisburg International Airport, Pennsylvania, (MDT); Over 10 miles from Harrisburg, Pennsylvania, (HAR) VORTAC on the 225° radial; Time – 0853 EDT (1253Z); Altitude – 9,500 ft; Type aircraft – Dassault Falcon 20; Temperature – -8° C; Icing – Light rime.

Routine pilot report (UA) MDT; Over 25 miles from HAR on the 315° radial; Time – 0855 EDT (1255Z); Altitude – 7,000 ft; Type aircraft – Cessna 208; Temperature – -7° C; Icing – Moderate mixed.

Routine pilot report (UA) UNV; Over UNV; Time – 0916 EDT (1316Z); Altitude – 4,000 ft; Type aircraft – Embraer 145; Temperature – -4° C; Icing – Light mixed; Remarks – Light mixed ice on approach.

Routine pilot report (UA) IAD; Over 35 miles from Armel, Virginia, (AML) VORTAC on the 015° radial; Time – 1030 EDT (1430Z); Altitude – 8,000 ft; Type aircraft – Bombardier CRJ200; Temperature – -5° C; Icing – Moderate rime; Remarks – In descent from 8,000 to 5,500 ft.

Routine pilot report (UA) Allegheny County Airport, Pennsylvania (AGC); Over half mile final from runway 28; Time – 1042 EDT (1442Z); Altitude – 200 ft; Type aircraft – Cessna 525; Remarks – +/- 10 knots in last 200 ft.

## 8.0 SIGMET

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

## 9.0 CWSU Products

There were no Center Weather Service Unit (CWSU) Center Weather Advisories (CWA) valid for the accident site at the accident time. There was a Meteorological Impact Statement (MIS) valid for the accident site at the accident time issued by the CWSU at the Cleveland (ZOB) Air Route Traffic Control Center (ARTCC) at 0653 EDT that was valid through 1400 EDT. The MIS warned of occasional severe icing below 10,000 ft for three quarters of the southwestern portion of ZOB airspace through 1200 EDT. Light to occasional moderate icing was forecast for between 2,000 and 16,000 ft with occasional moderate turbulence at or below 8,000 ft. Areas of IFR to isolated LIFR were forecast in areas of light snow for the southern two thirds of ZOB airspace with widespread ceilings below 5,000 ft across the rest of ZOB airspace:

FAUS20 KZOB 191053
ZOB MIS 01 VALID 191053-191800
**...FOR ATC PLANNING PURPOSES ONLY...**
**SW 3/4 ZOB.. OCNL SEVERE ICE BLW 100 ENDG BY 16Z. ENTIRE ZOB..**
**LGT-OCNL MOD ICE 020-160. OCNL MOD TURB FL200-390 AND AOB 080. S 2/3**
**ZOB.. AREAS IFR-ISOL LIFR -SN TIL 16Z. ENTIRE ZOB EXCPT E-CNTRL MI..**
**WDSPR CIG BLW 050.. DCRG EXTRM W ZOB AFT 16Z.**
**=**

## 10.0 AIRMETs

Airmen's Meteorological Information (AIRMET) advisories Sierra, Tango, and Zulu were valid for the accident site at the accident time for below FL180. The AIRMETs warned of IFR conditions due to precipitation and mist, mountain obscuration conditions due to clouds, precipitation, and mist, moderate icing between freezing level and 16,000 ft (or FL180, accident location was on the border of both AIRMET Zulu advisories), and moderate turbulence below 8,000 ft:

WAUS41 KKCI 191126 AAA
WA1S
-BOSS WA 191126 AMD
AIRMET SIERRA UPDT 2 FOR IFR AND MTN OBSCN VALID UNTIL 191500
.
**AIRMET IFR...NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA AND CSTL WTRS**
**FROM 60WSW YSC TO 50ESE BOS TO 120SE ACK TO 30NE HAR TO 30NNE HMV TO 40S HNN TO 60E CVG TO CVG TO FWA TO 20NE DXO TO 40NNW CLE TO 30SE YOW TO 60WSW YSC**
**CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG BYD 15Z THRU 21Z.**
.
**AIRMET MTN OBSCN...ME NH VT MA NY PA WV MD VA NC...UPDT**
**FROM 70NW PQI TO MLT TO CON TO HAR TO 20ESE PSK TO 30WNW SPA TO VXV TO HMV TO HNN TO JHW TO SYR TO MSS TO YSC TO 70NW PQI**
**MTNS OBSC BY CLDS/PCPN/BR. CONDS CONTG BYD 15Z THRU 21Z.**
**.**
OTLK VALID 1500-2100Z...IFR ME NH VT MA RI CT NY NJ PA WV MD DC
DE VA AND CSTL WTRS
BOUNDED BY 50WSW YSJ-170ESE ACK-110SSE HTO-20ENE ETX-50SW EKN-20SW EWC-20ESE SYR-BOS-50WSW YSJ
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG THRU 21Z.
....

WAUS41 KKCI 191127 AAA
WA1Z
-BOSZ WA 191127 AMD
AIRMET ZULU UPDT 3 FOR ICE AND FRZLVL VALID UNTIL 191500
.
AIRMET ICE...ME NH VT NY LO
FROM 70NW PQI TO 60NE PQI TO 60WSW YSJ TO 50ESE MSS TO 20NE BUF TO 30SE ECK TO YOW TO YSC TO 70NW PQI
MOD ICE BLW 120. CONDS CONTG BYD 15Z THRU 21Z.
.
**AIRMET ICE...ME NH VT MA RI CT NY LO NJ PA OH WV MD DC DE VA AND CSTL WTRS**
**FROM 60WSW YSJ TO 150ESE ACK TO 30SSW CYN TO 40SSW CSN TO HNN TO EKN TO 30SSW PSB TO 40NNE SLT TO 20NNE BUF TO 40SE MSS TO 60WSW YSJ**
**MOD ICE BTN FRZLVL AND FL180. FRZLVL SFC-080. CONDS CONTG BYD 15Z THRU 21Z.**
**.**
**AIRMET ICE...NY LO PA OH LE WV MD**
**FROM 20NNE BUF TO 30NNE SLT TO 30SSW PSB TO EKN TO HNN TO CVG TO FWA TO 30SE ECK TO 20NNE BUF**
**MOD ICE BTN FRZLVL AND 160. FRZLVL SFC-020. CONDS ENDG 12-15Z.**

.
AIRMET ICE...WV VA
FROM HNN TO 40SSW CSN TO 20SSE LYH TO 40S PSK TO HMV TO HNN
MOD ICE BTN FRZLVL AND 100. FRZLVL 020-040. CONDS CONTG BYD 15Z
ENDG 15-18Z.
.
OTLK VALID 1500-2100Z...ICE ME NH VT MA RI CT NY NJ PA OH WV MD
DC DE VA AND CSTL WTRS
BOUNDED BY 50WSW YSJ-150ESE ACK-90SSE ACK-150SSE
HTO-ORF-HNN-EKN-30SSW PSB-40NNE SLT-MPV-60W BGR-50WSW YSJ
MOD ICE BTN FRZLVL AND FL180. FRZLVL SFC-080. CONDS CONTG THRU
21Z.
.
FRZLVL...RANGING FROM SFC-130 ACRS AREA
  MULT FRZLVL 020-090 BOUNDED BY 80SSW YSJ-160ESE ACK-30E HTO-
    20NNE CYN-20ESE ETX-20S PSB-20NNW SLT-40ENE ALB-20WNW CON-
    50E ENE-80SSW YSJ
  MULT FRZLVL 030-130 BOUNDED BY EKN-LYH-GSO-20NNW SPA-40S GQO-
    GQO-HMV-HNN-EKN
  SFC ALG 20NE DXO-50SE ECK-20ENE JHW-30N ALB-MPV-70ENE YQB
  040 ALG 30N HMV-20WNW EMI-40ENE SAX-70NE ACK-140ENE ACK
  080 ALG 30NE GSO-40ENE RIC-50SSW HTO-50ESE HTO-140ESE ACK
  120 ALG 160SE SIE-180ESE SIE-200S ACK
....

WAUS41 KKCI 190845
WA1T
-BOST WA 190845
AIRMET TANGO UPDT 1 FOR TURB AND LLWS VALID UNTIL 191500
.
AIRMET TURB...ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA
NC SC AND CSTL WTRS
FROM 70NW PQI TO 60NE PQI TO 130ENE ACK TO 50ENE RDU TO 30NE ODF
TO 30ENE GQO TO HMV TO HNN TO CVG TO FWA TO 30SE ECK TO YOW TO
YSC TO 70NW PQI
MOD TURB BTN FL200 AND FL390. CONDS CONTG BYD 15Z THRU 21Z.
.
AIRMET TURB...ME NH VT MA RI CT NY NJ PA OH WV MD DC DE VA AND
CSTL WTRS
FROM 50SW YSJ TO 200SE ACK TO 20S EKN TO 40NNW ALB TO 60SSW MPV
TO 50SW YSJ
MOD TURB BTN 080 AND FL200. CONDS CONTG BYD 15Z ENDG 18-21Z.
.
**AIRMET TURB...NH VT MA CT NY LO NJ PA OH LE WV MD DE VA**
**FROM 30WSW YOW TO 40NNW ALB TO 20S EKN TO HNN TO CVG TO FWA TO**
**30SE ECK TO 30WSW YOW**
**MOD TURB BLW 080. CONDS CONTG BYD 15Z THRU 21Z.**
.
AIRMET TURB...MA RI NY NJ PA OH WV MD DC DE VA NC SC GA AND CSTL
WTRS
FROM 190SE ACK TO 160SE SIE TO 190ESE ECG TO 130SSE ILM TO 40WNW
PZD TO GQO TO HMV TO HNN TO 20S EKN TO 190SE ACK
MOD TURB BLW 120. CONDS CONTG BYD 15Z THRU 21Z.
.
LLWS POTENTIAL...WV MD VA NC SC GA
BOUNDED BY 40SE AIR-50NW CSN-30WNW CLT-20NNE ATL-GQO-HMV-40SE AIR

LLWS EXP. CONDS DVLPG 09-12Z. CONDS CONTG BYD 15Z ENDG 15-18Z.
.
LLWS POTENTIAL...NJ PA MD DC DE VA NC SC GA FL AND CSTL WTRS
BOUNDED BY 30SSE HAR-30WSW CYN-40SSE SIE-100SE ECG-40W CRG-50SW
PZD-20NW PZD-ATL-30WNW CLT-30SSE HAR
LLWS EXP. CONDS ENDG 12-15Z.
.
OTLK VALID 1500-2100Z
AREA 1...TURB 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 70NW PQI-60NE PQI-130E ACK-110SE ACK-ECG-30S CLT-ODF-
20E GQO-HMV-HNN-CVG-FWA-30SE ECK-YOW-YSC-70NW PQI
MOD TURB BTN FL240 AND FL390. CONDS CONTG THRU 21Z.
.
AREA 2...TURB NH VT MA CT NY LO NJ PA OH LE WV MD DE VA AND CSTL
WTRS
BOUNDED BY 20NNE YYZ-20WNW CON-20SW HTO-20ESE CYN-40S HNN-HNN-
CVG-FWA-30SE ECK-20NNE YYZ
MOD TURB BLW 080. CONDS CONTG THRU 21Z.
....

## 11.0 Graphical Forecasts for Aviation

The Graphical Forecasts for Aviation (GFA) products issued at 0600 EDT for 0800 and 1100 EDT prior to the accident airplanes departure indicated overcast cloud cover with bases between 2,500 ft and 3,000 ft msl, with tops near 9,000 ft at 0800 EDT and cloud cover between 2,000 and 12,000 ft msl at 1100 EDT with a few areas of clear skies across central Pennsylvania (attachment 5). The GFA surface forecast indicated MVFR[38] to LIFR conditions with likely (greater than 60 percent chance) rain showers and snow showers, and a surface wind from the west between 15 to 20 knots (attachment 5). The reason for the differences between the GFA surface forecast and the aviation cloud forecast is the two are computed automatically by two different weather models (attachment 6). The Rapid Refresh (RAP) weather model is used for the aviation cloud forecast and the Localized Aviation MOS[39] Program (LAMP) weather model is used for the surface forecast charts, and both forecasts are issued with no human intervention (attachment 6). The only human-generated information reflected in the two GFA products are the AIRMETs and the GFA is human-over-the-loop.

## 12.0 Terminal Aerodrome Forecast

KAOO was the closest airport to the accident site with an amended NWS Terminal Aerodrome Forecast (TAF). The KAOO TAF valid at the time of the accident was issued at 0818 EDT and was valid for a 24-hour period beginning at 0800 EDT. The TAF for KAOO was as follows:

[38] Marginal Visual Flight Rules – Refers to the general weather conditions pilots can expect at the surface. MVFR criteria means a ceiling between 1,000 and 3,000 ft agl and/or 3 to 5 miles visibility.
[39] Model Output Statistics: https://www.weather.gov/mdl/mos_home

TAF AMD KAOO 191218Z 1912/2012 **31007KT 1SM -RA BR BKN012 OVC035**
FM191330 32013G25KT 2SM -RASN BR OVC012
FM191400 31015G27KT 3SM -SHSN BR OVC015
FM191800 31018G30KT P6SM OVC025
FM192000 32018G30KT P6SM BKN035
FM200400 31015G25KT P6SM BKN035=

After 0800 EDT, the forecast expected a wind from 310° at 7 knots, 1 mile visibility, light rain and mist, a broken ceiling at 1,200 ft agl, and overcast skies at 3,500 ft agl.

## 13.0 NWS Area Forecast Discussion

The NWS office in State College, Pennsylvania, issued the following Area Forecast Discussion (AFD) at 0729 EDT (closest AFD to the accident time). The aviation section of the AFD discussed areas of rain in the eastern portion of central Pennsylvania and areas of light snow and fog in the western portion of central Pennsylvania with the TAFs updated to reflect the precipitation and current conditions:

FXUS61 KCTP 191129
AFDCTP

Area Forecast Discussion
National Weather Service State College PA
729 AM EDT Thu Apr 19 2018

.SYNOPSIS...
A rather compact but potent low pressure area will move east from the Ohio Valley and take aim on the Laurel Highlands and adjacent portions of Central and Southern Pennsylvania today. Occasional light snow or snow showers will bring a light accumulation of a coating to around one inch to the higher terrain of northern and western Pennsylvania today. The ridge tops of the Laurel Highlands could see locally higher amounts of around 2 inches. Blustery conditions and unseasonably cold temperatures will occur Today and Friday. A prolonged period of dry weather and slowly moderating temperatures will follow for the upcoming weekend through at least the first part of next week as a large area of high pressure drifts from the Upper Midwest to the New England states.

&&

.NEAR TERM /UNTIL 6 PM THIS EVENING/...
Current system affecting the region today displays a much more detached warm/cold conveyor belt and lighter associated QPF than was advertised by a host of short range model guidance at this time Wednesday morning. Additionally, the sfc low is weaker by 2-4 mb and more fragmented while taking a more southern track across the Virginias (than previously depicted).

These notable changes have impacted (lessened both our snowfall and wind forecasts). Recently dropped the Winter Weather Advisory that was in place across our northern tier, since the warm

advection snows likely only accumulated one half of an inch at best considering borderline temps and just a 60-90 minute period that afforded the chc for briefly moderate snowfall rates between 05-08Z.

The main (and quite compact) cold conveyer belt snows falling across NE Indiana and Northern Ohio ATTM, will slide ESE through the rest of this morning, and should spread over the Laurel Highlands and bring a coating to 2 inches of snow accum between about 12-16Z today. Elsewhere, any steadier precip will be brief or non-existent today, though much colder temps advecting into the region within the 850-500 mb layer will steepen lapse rates and generate scattered-numerous snow showers across the Mountains of North-Central and NW PA through early this afternoon with perhaps a coating...up to around an inch on grassy areas across the higher elevations.

Expect much of the precip to the SE of the Allegheny Plateau to remain rain through the mid morning hours, but the higher elevations and over the Plateau will go to wet snow, (or at the very least a mix).

SLRs will be less than 8:1 = a fairly wet snow. The heaviest rain (that will exit the SE third of our CWA over the next few hours) will occur within the preferred lift/thermally indirect cell associated with the left exit region of the quite strong upper level jet max (over 100 Kt at 300 MB).

The middle of the road numbers mixing down the wind speeds over the Laurels and SC Mtns yields some gusts of 25-35kts. This shouldn't be nearly enough to necessitate a wind advy.

&&

.SHORT TERM /6 PM THIS EVENING THROUGH 6 AM FRIDAY/...
Temps only rise a deg or two today as CAA and wrap around clouds make it difficult to take advantage of the mid-April solar potential.

If they even drop a deg or two, the precip over most of the area my be snow. But, will still call it mainly a rain/snow mix for the lower elevations. While some additional accums are possible Thurs, the main place to have anything stick will be those that have the snow already on the ground in the morning and the very highest elevations of the rest of the area.

The gusty wind mentioned before will last much of the day across the southern third of the area and the north will ramp up to 25-30kt gusts at times. A blustery day for sure. A secondary push of colder air looks like it will cross the eastern zones under the aforementioned sharp upper trough, and could make quite a few showers for places just east of the Susq River. The temps may even be cold enough on the hill tops of the Poconos/Schuylkill Co to make snow stick.

Post-frontal/cyclonic flow stratus/strato-cu remain for much of

Thurs PM and a well-mixed lower atmos will keep the temps from dropping too far. So, the departure from normal mid-April values is only going to be a negative 5 to 10F.

&&

.LONG TERM /FRIDAY THROUGH WEDNESDAY/...
Shallow stratocu and flurries will persist across the NW half of the state Thursday night and early Friday, with partly cloudy skies in the SE. Winds should stay up enough through daybreak Friday to prevent a frost or freeze in the SE zones, while lows elsewhere dip into the mid 20s to low 30s.

Friday and beyond, there will be a welcome break of lighter wind, sunshine and milder temps as a large area of high pressure moves out of the midwest.

Yet another upper low in this busy pattern looks to drop into the deep south toward the end of the period. This may spread some precipitation northward toward our region for the beginning of next week.

&&

**.AVIATION /12Z THURSDAY THROUGH MONDAY/...**
**The area of rain east of the area as of 6 AM. Movement was about 50 mph to the northeast.**

**Some fog and real light snow to the west.**

**12Z TAFs adjusted for the above factors.**

**Main thing laker today will be gusty winds.**

**Conditions improve drastically Fri with the arrival of a big high pressure area which will last through the weekend.**

Outlook...

Fri...MVFR cigs nw 1/3; VFR elsewhere.

Sat-Mon...VFR/no sig wx.

&&

.CTP WATCHES/WARNINGS/ADVISORIES...
None.

&&

$$

## 14.0 Winds and Temperature Aloft Forecast

The NWS 0401 EDT Winds and Temperature Aloft forecast valid for the closest point to the accident site is included below:

```
FBUS31 KWNO 190801
FD1US1
DATA BASED ON 190600Z
VALID 191200Z   FOR USE 0800-1500Z. TEMPS NEG ABV 24000

FT  3000    6000    9000   12000   18000   24000  30000  34000  39000
PSB      2620-01 2651-06 2564-10 2567-19 2472-30 249043 248846 257847
```

The accident site was located closest to the PSB forecast point. The 0401 EDT PSB forecast for use between 0400 EDT and 1100 EDT indicated a wind at 6,000 ft from 260° at 20 knots with a temperature of -1° C and a wind at 9,000 ft from 260° at 51 knots with a temperature of -6° C.

## 15.0 Pilot Weather Briefing and Witness Information

The accident pilot did not request a weather briefing from Leidos or DUATS, however, Leidos does have a record of the weather briefing the accident pilot requested through ForeFlight and the flight plan filed therein.

A search of archived ForeFlight information indicated that the accident pilot did request weather information via ForeFlight. The accident pilot filed a flight plan and got an associated weather briefing at 2127 EDT on April 18 (attachment 7). The ForeFlight weather briefing contained all the standard weather information valid for a departure time of 0645 EDT on April 19, but not all of the weather forecast products (e.g. current AIRMETs, SIGMETs, TAFs, etc…) provided abundant weather information for the accident route so far in advance of the flight. For example, the AIRMETs were only valid through 0500 EDT on April 19. However, the GFA products issued around 2100 EDT on April 18 did have some valid products still available at 0800 and 1100 EDT on April 19 (attachment 7). Cloud cover as low as 2,000 ft msl was forecast along the route of flight in the GFA products from 2100 EDT on April 18 (with cloud tops to 12,000 ft), but the GFA aviation surface forecast had at worst only MVFR conditions with likely (greater than 60 percent chance) snow shower activity (attachment 7). IFR and LIFR conditions were forecast between 0200 and 1000 EDT on April 19 in the KAOO and KJST TAFs issued around 2000 EDT on April 18. Updated AIRMET and SIGMET advisories from as late as 0452 EDT on April 19 were recorded via the flight plan id number (attachment 9), but it is unknown if the accident pilot checked the updated AIRMET and SIGMET information before the flight. With no internet access while in flight, ForeFlight is still able to access weather information directly from the FAA, but leaving no remote record of such access. For more information please see attachments 7, 8, and 9.

There is no record of the accident pilot receiving or retrieving any other weather information before or during the accident flight.

## 16.0 ATC Information

The NTSB asked JST ATC, "how does JST ATC receive KAOO METAR information?" JST ATC stated the JST air traffic controllers receive KAOO METAR and SPECI reports to include the full KAOO weather information, including the remarks section. JST air traffic controllers are trained to read the pertinent weather sections of the remarks, but that they do not decode any of the number values. In this case, the numbers beyond the variable ceiling in the remarks section that include:

1. (P0001) liquid-equivalent precipitation accumulated during the last hour
2. (T00610044) breakdown of the temperature and dew point in eight digits separated into two groups of four
3. ($) maintenance check indicator
4. (=) end of METAR

For more information please see the NTSB ATC factual and record of conversation in the docket for this accident.

## 17.0 Icing Potential[40]

Current Icing Potential (CIP) and Forecast Icing Potential (FIP) products are created by the NWS Aviation Weather Center (AWC) and are intended to be supplemental to other icing advisories (e.g. AIRMETs and SIGMETs). Figures 23 through 25 were the FIP icing probabilities and icing severity products, 1-hour forecast valid at 0900 EDT at 4,000, 5,000, and 6,000 ft msl (similar FIP values are seen in the 2-hour forecast valid at both 0800 and 0900 EDT, attachment 10). The FIP images indicated between a 50 to 70% probability of icing at 4,000 to 6,000 ft at 0900 EDT above the accident site (figures 23, 24, and 25). The FIP also indicated that the icing near the accident site would likely be trace to moderate (figures 23, 24, and 25). The FIP indicated a 40 to 50% probability of Supercooled Large Droplet (SLD) over the accident area around the accident time at 6,000 ft (attachment 10). This FIP information would have been publicly available on the NWS AWC website before the accident flight departed.[41]

The CIP product indicated between a 60 to 85% probability of icing at 4,000 to 6,000 ft at 0900 EDT at the accident site (figures 26, 27, and 28). The CIP also indicated that the icing near the accident site would likely be light to moderate intensity between 4,000 and 6,000 ft (figures 26, 27, and 28). The CIP also indicated a 10 to 40% chance of SLD near the accident site at 0900 EDT between 4,000 and 6,000 ft and a 0 to 40% of SLD near the accident site at 0800 EDT between 4,000 and 6,000 ft (attachment 10). For more FIP and CIP data please see attachment 10.

---

[40] B.C. Bernstein, F. McDonough, M. K. Politovich, B. G. Brown, T. P. Ratvasky, D. R. Miller, C.A. Wolff, and G. Cunning, Current Icing Potential: Algorithm Description and Comparison with Aircraft Observations (Journal of Applied Meteorology, 2005), pp. 969-986.
C.A. Wolff, F. McDonough, M. K. Politovich, B.C. Bernstein, and G. Cunning, FIP Severity Technical Document (Prepared for the Aviation Weather Technology Transfer Technical Review Board), pp. 1-44.
https://arc.aiaa.org/doi/abs/10.2514/6.2009-3531

[41] https://www.aviationweather.gov/icing/fip

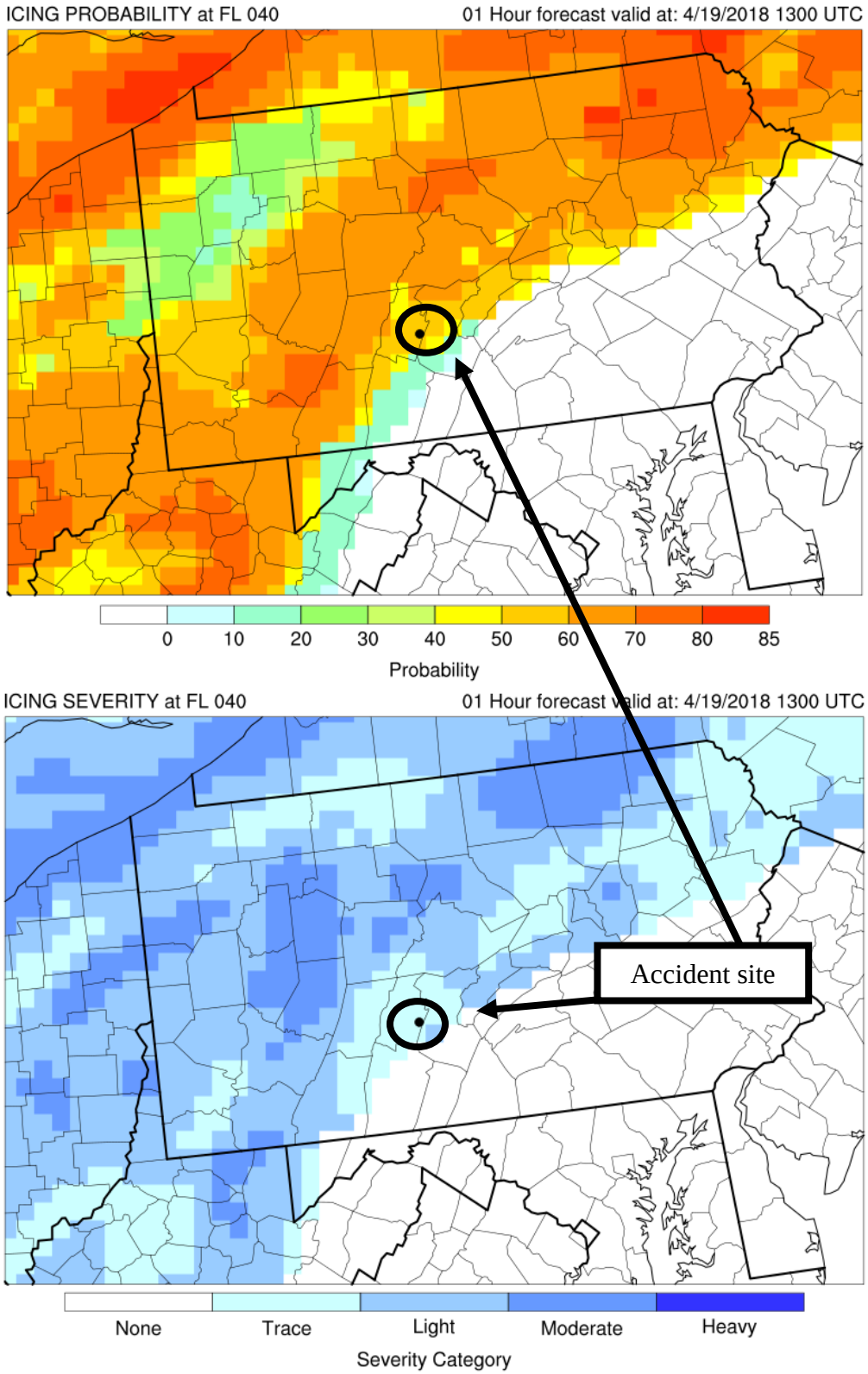



**Figure 23 – (top) FIP probability of icing at 4,000 ft msl and (bottom) FIP severity of icing at 4,000 ft msl 1-hour forecast valid for 0900 EDT**

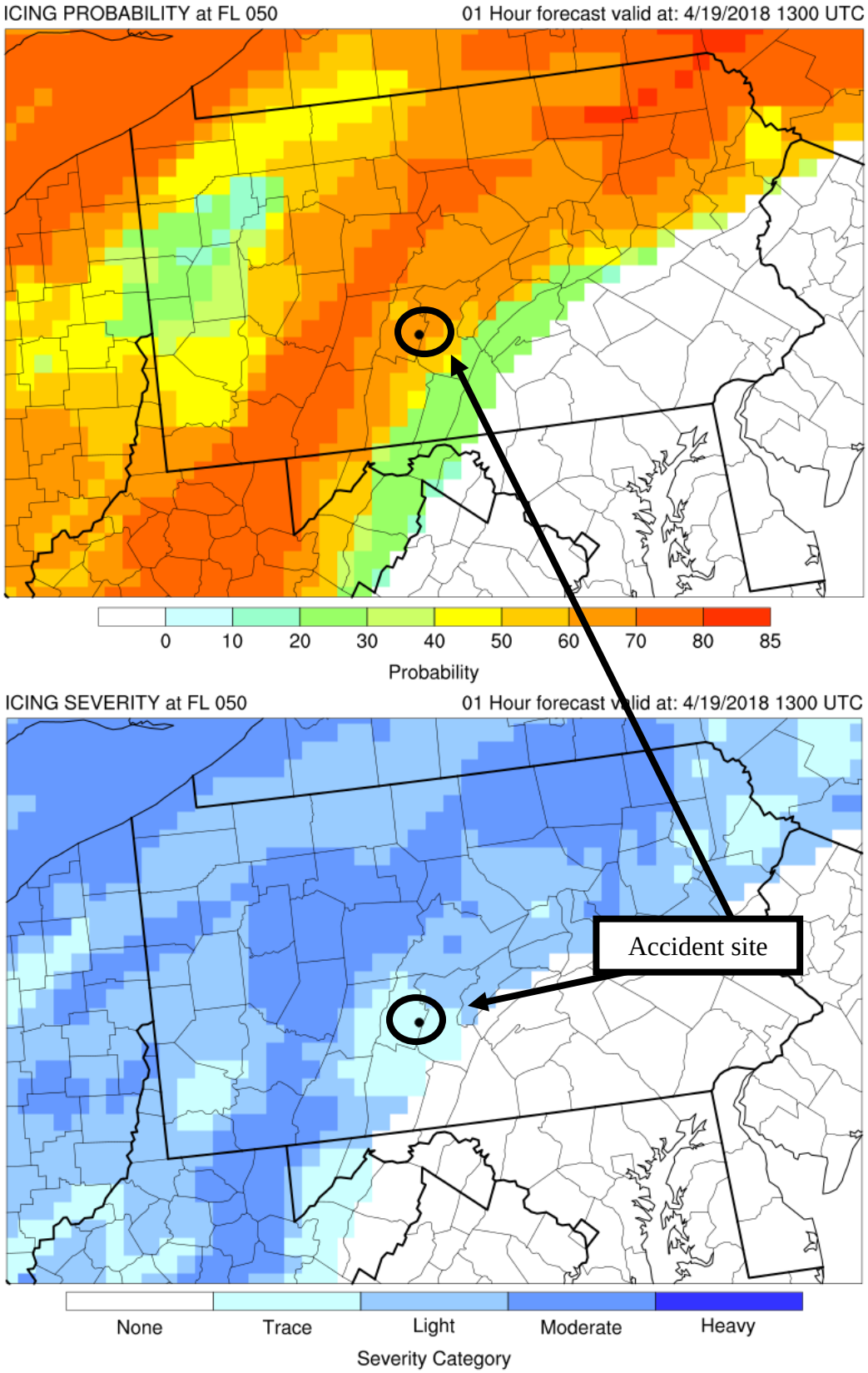



**Figure 24 – (top) FIP probability of icing at 5,000 ft msl and (bottom) FIP severity of icing at 5,000 ft msl 1-hour forecast valid for 0900 EDT**

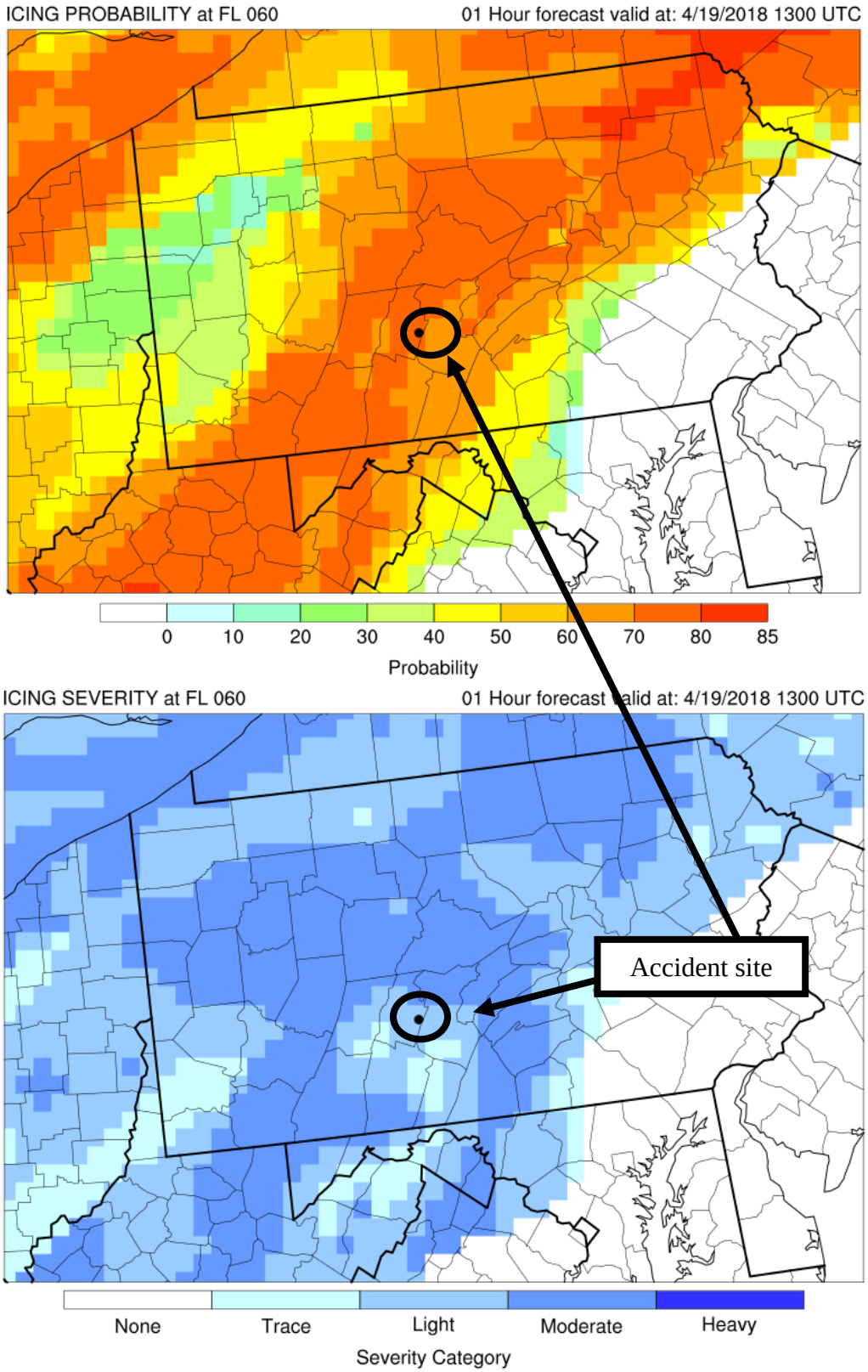



**Figure 25 – (top) FIP probability of icing at 6,000 ft msl and (bottom) FIP severity of icing at 6,000 ft msl 1-hour forecast valid for 0900 EDT**

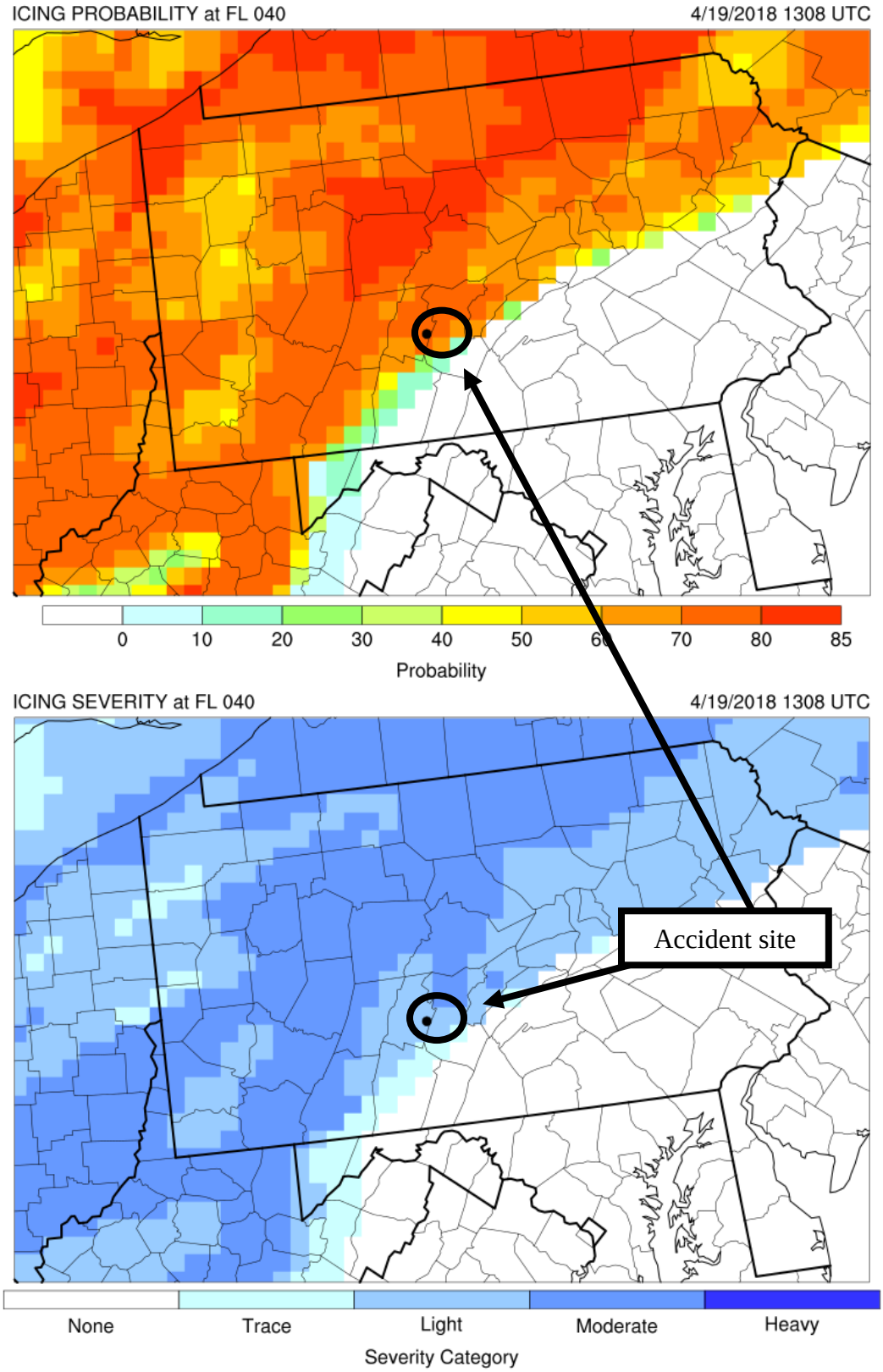



**Figure 26 – (top) CIP probability of icing at 4,000 ft msl and (bottom) CIP severity of icing at 4,000 ft msl valid for 0900 EDT**

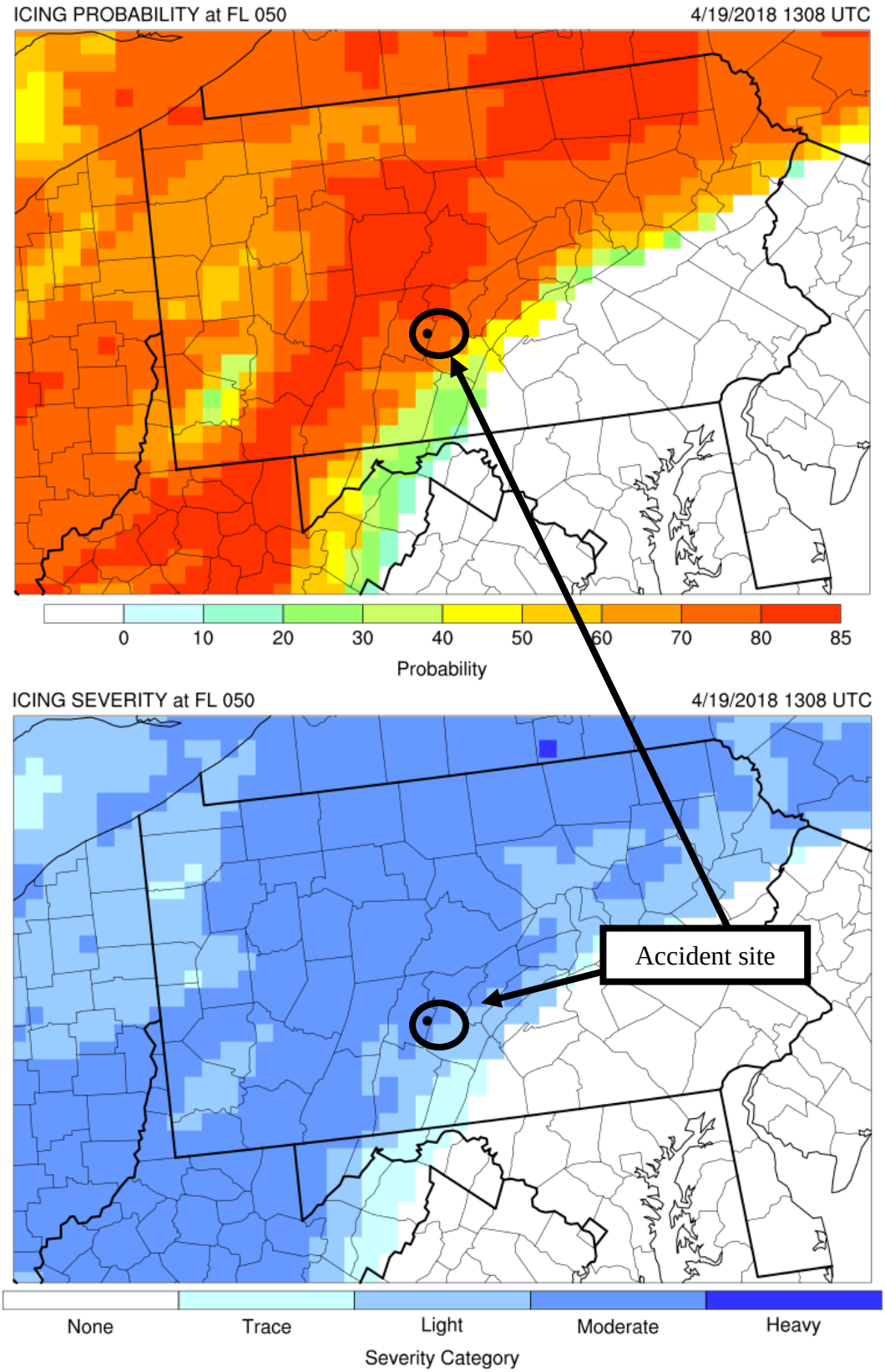



**Figure 27 – (top) CIP probability of icing at 5,000 ft msl and (bottom) CIP severity of icing at 5,000 ft msl valid for 0900 EDT**

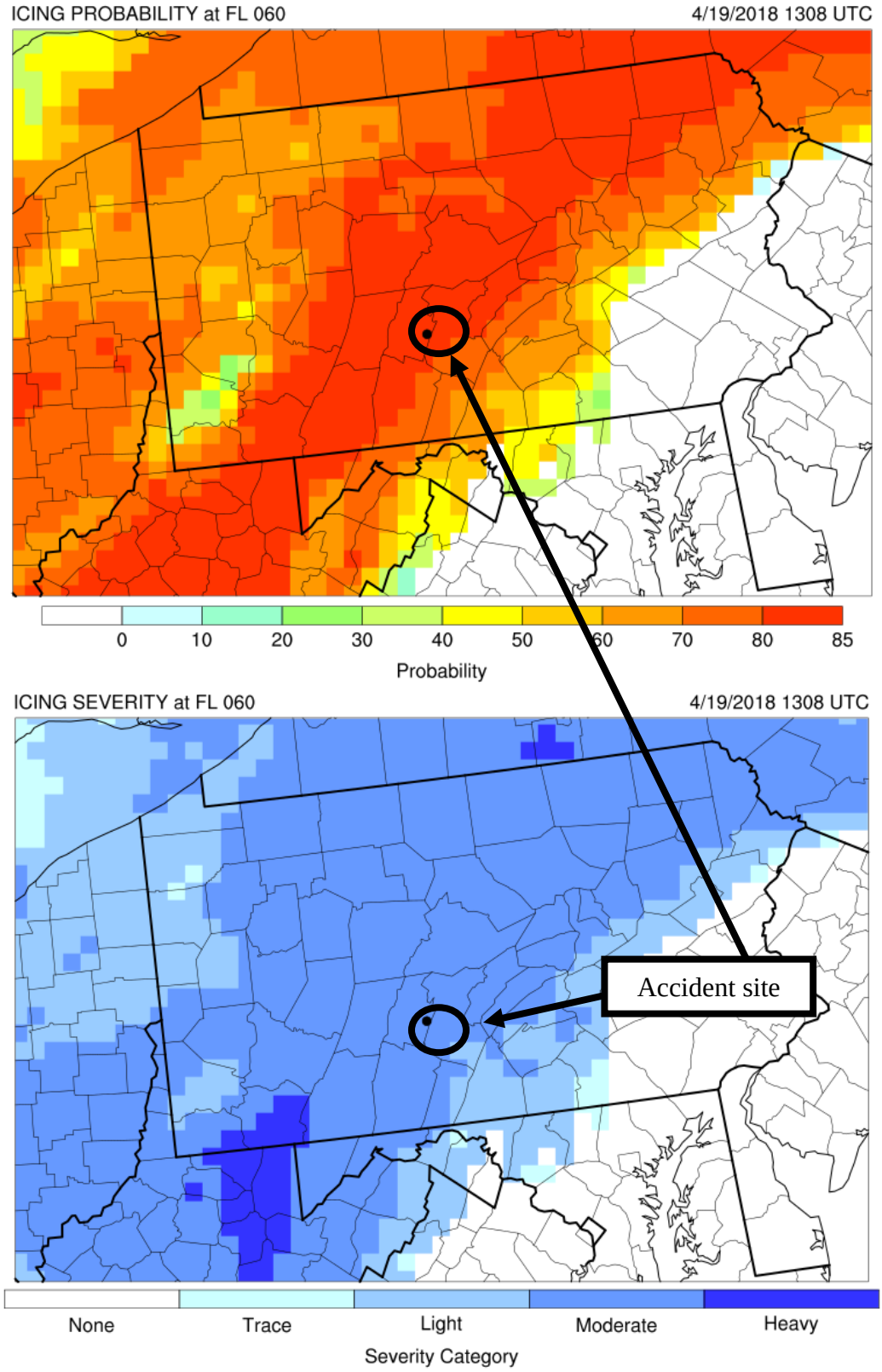



**Figure 28 – (top) CIP probability of icing at 6,000 ft msl and (bottom) CIP severity of icing at 6,000 ft msl valid for 0900 EDT**

## 18.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on April 19, 2018, indicated the following:

| **SUN** | |
|---|---|
| Begin civil twilight | 0600 EDT |
| Sunrise | 0629 EDT |
| **Accident time** | **0843 EDT**[42] |
| Sun transit | 1312 EDT |
| Sunset | 1956 EDT |
| End civil twilight | 2025 EDT |

## E. LIST OF ATTACHMENTS

Attachment 1 – GOES-16 Visible animation from 0732 to 1032 EDT

Attachment 2 – NASA SPoRT Daytime Microphysics RGB quick guide

Attachment 3 – GOES-16 Daytime Microphysics RGB animation from 0732 to 1032 EDT

Attachment 4 – GOES-16 Infrared + visible sandwich imagery animation for the accident flight with ATC transcript overlaid

Attachment 5 – GFA products valid for the accident site around the accident time and before the accident flight departed LNS

Attachment 6 – Correspondence with the Aviation Weather Center regarding GFA products

Attachment 7 – Correspondence with the ForeFlight regarding weather briefing

Attachment 8 – Record of ForeFlight weather briefing from Leidos

Attachment 9 – Record of ForeFlight filed flight plan from Leidos

Attachment 10 – CIP and FIP products valid at 0800 and 0900 EDT for the accident flight

Submitted by:

_____

Paul Suffern
Senior Meteorologist

[42] Inserted accident time for reference and context.

**THIS PAGE INTENTIONALLY BLANK**