



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

August 30, 2018

Factual Report

METEOROLOGY

DCA18MA142

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A. ACCIDENT

Location: Philadelphia, Pennsylvania
Date: April 17, 2018
Time: 1103 eastern daylight time
1503 Coordinated Universal Time (UTC)
Aircraft: Southwest Airlines flight 1380, Boeing 737-700, Registration: N772SW

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 17, 2018, and are based upon the 24-hour clock, where local time is -4 hours from UTC, and UTC=Z. 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 coordinates used for the accident site were latitude 40.4411° N, longitude 76.2373° W, at FL320.¹

¹ Flight Level – A Flight Level (FL) is a standard nominal altitude of an aircraft, in hundreds of feet. This altitude is calculated from the International standard pressure datum of 1013.25 hectopascals (hPa) (29.92 inches of mercury) and 15° Celsius (C), the average sea-level pressure, and therefore is not necessarily the same as the aircraft's true altitude either above mean sea level or above ground level.

D. 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.²

1.1 Surface Analysis Chart

The northeastern United States section of the NWS Surface Analysis Chart for 1100 EDT is provided as figure 1 with the approximate location of the accident site marked within the red circle. The chart depicted an extensive area of overcast clouds over the region with light westerly winds and snow reported at the surface from western New York southwestward into western Pennsylvania, and Ohio. No frontal boundaries or areas of surface low or high pressure were located near the accident site at 1100 EDT.

The surface station observations around the accident site depicted air temperatures in the upper 30’s to mid 40’s degrees Fahrenheit (°F), dew point temperatures in the upper 20’s °F with temperature-dew point spreads of 9° F or more, a southwest to west wind of 10 to 15 knots, overcast sky cover, and light rain reported in central Pennsylvania.

²

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

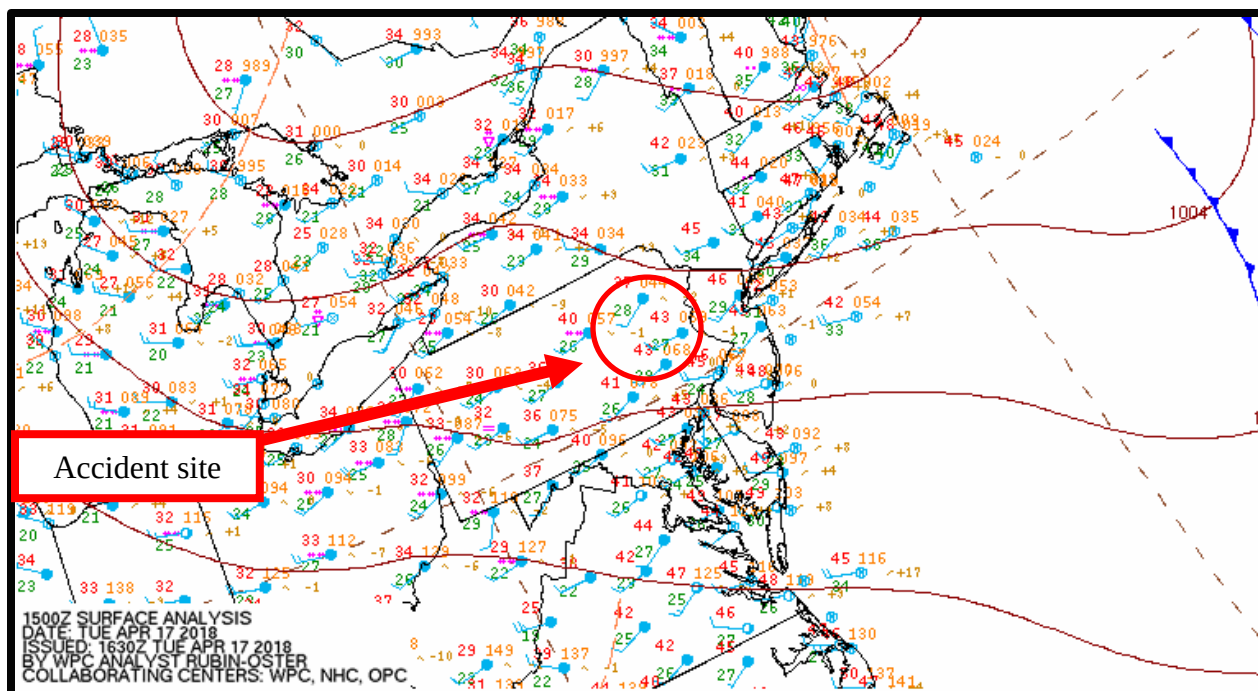


Figure 1 – NWS Surface Analysis Chart for 1100 EDT

1.2 Upper Air Charts

The NWS Storm Prediction Center (SPC) Constant Pressure Charts for 0800 EDT at 925-, 850-, 700-, 500-, and 300- hectopascals (hPa) are presented in figures 2 through 6. There were low-level troughs³ located in the northeastern United States and over the Great Lakes region. There was a mid- and upper level trough located northeast of the accident site over the Northeastern United States. Troughs can act as lifting mechanisms to help produce clouds and precipitation if sufficient moisture is present. There was a west wind of 20 knots at 925-hPa with the wind becoming west-southwesterly by 700-hPa (figure 4). By 300-hPa, the wind was from the west-northwest at 55 knots (figure 6).

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

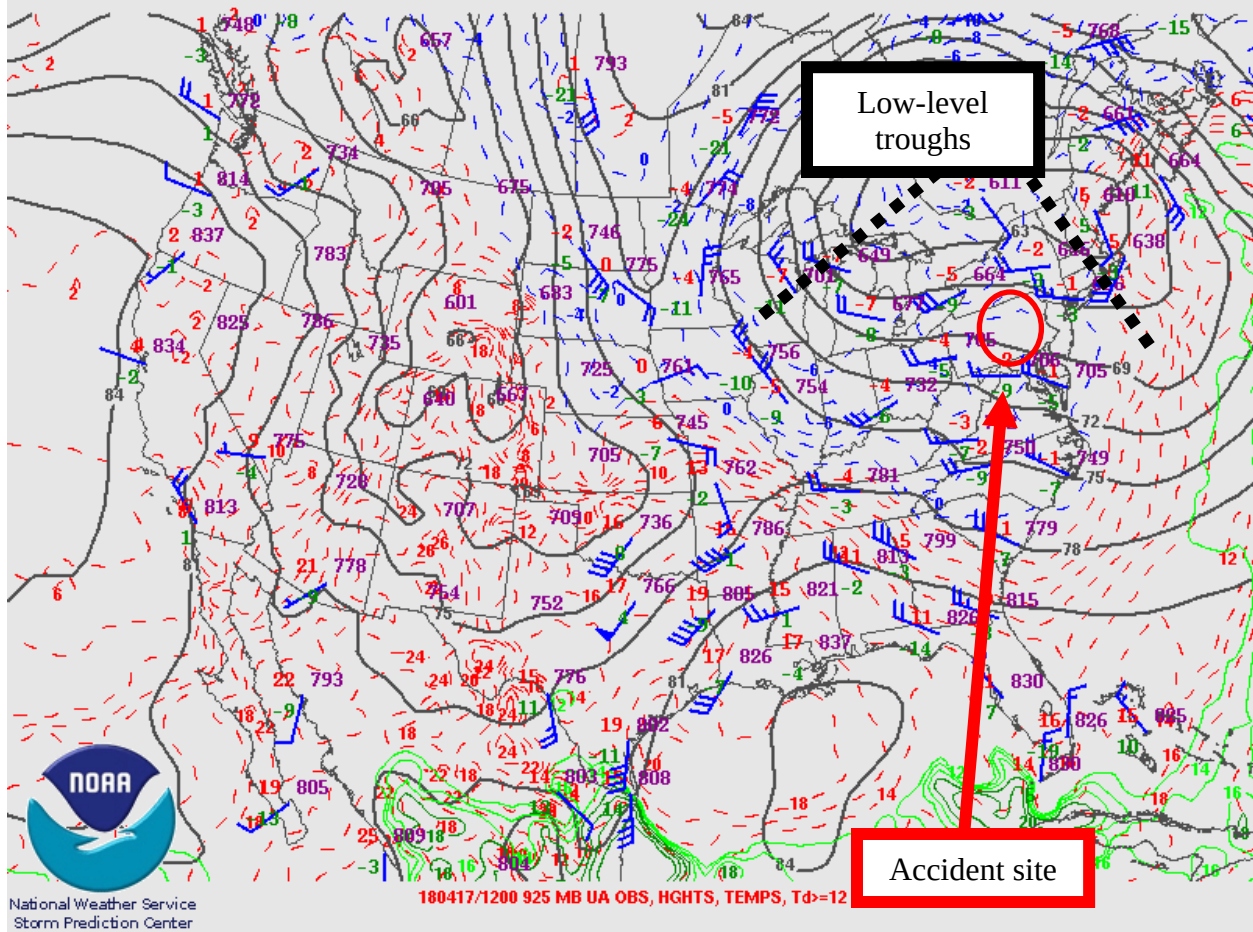


Figure 2 – 925-hPa Constant Pressure Chart for 0800 EDT

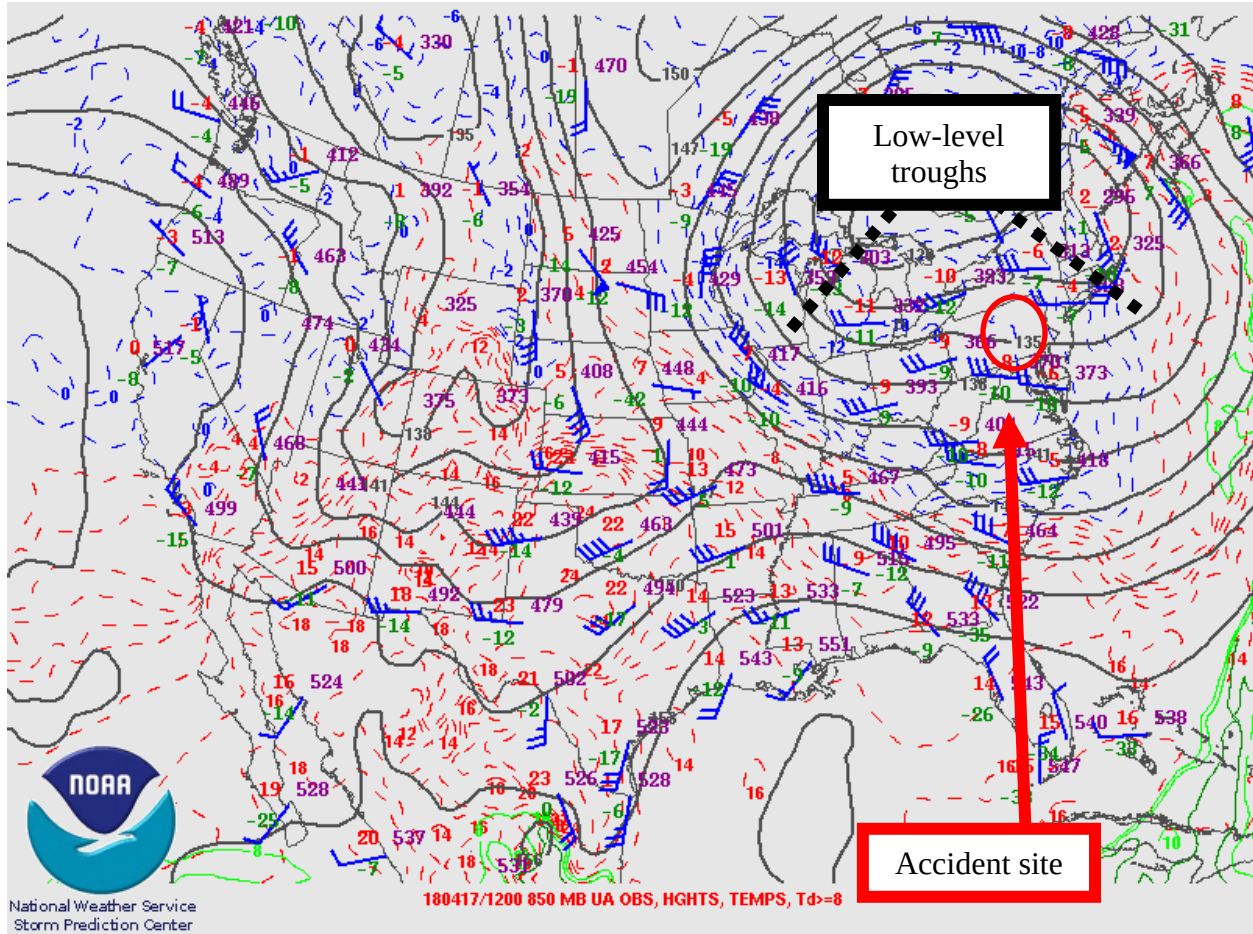


Figure 3 – 850-hPa Constant Pressure Chart for 0800 EDT

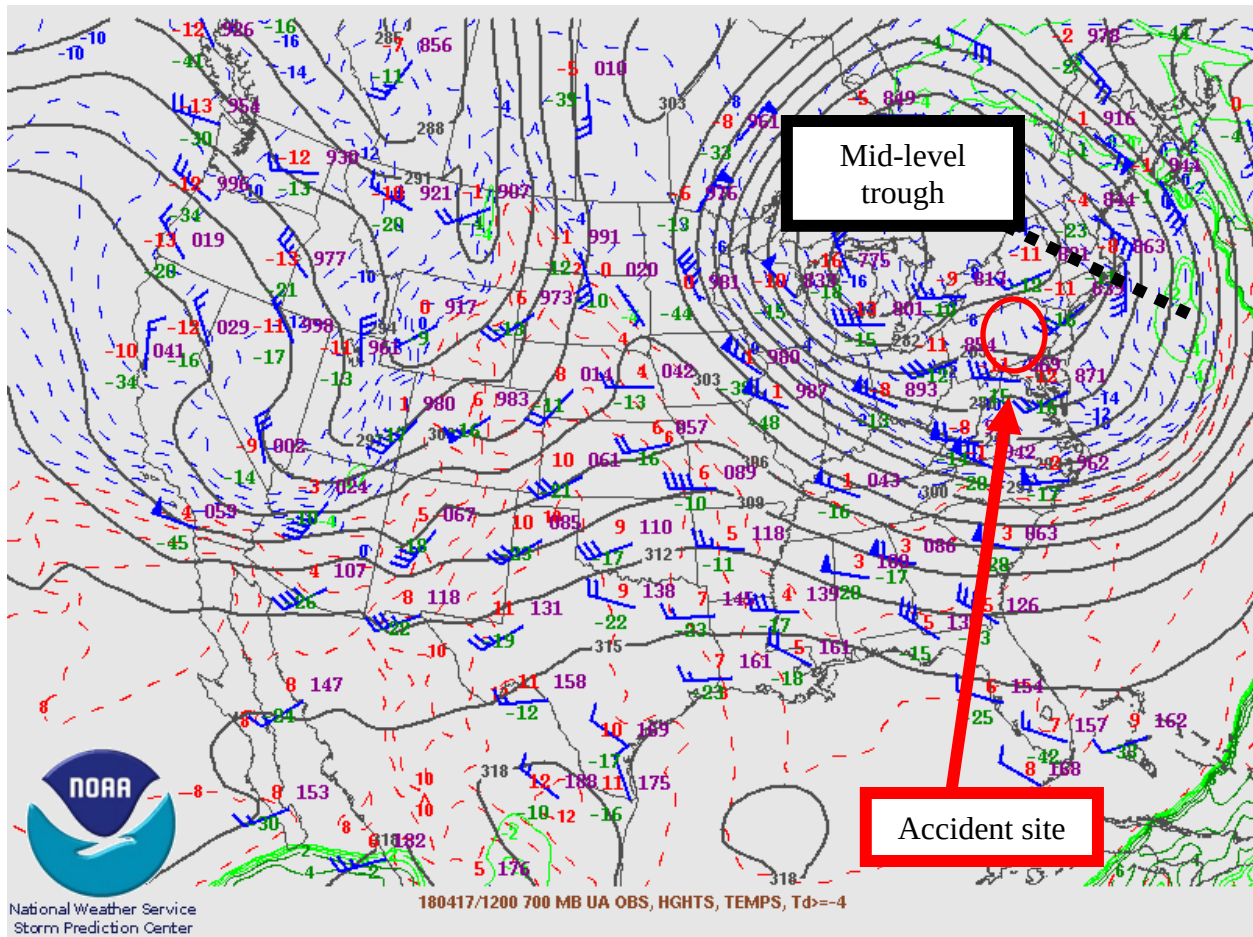


Figure 4 – 700-hPa Constant Pressure Chart for 0800 EDT

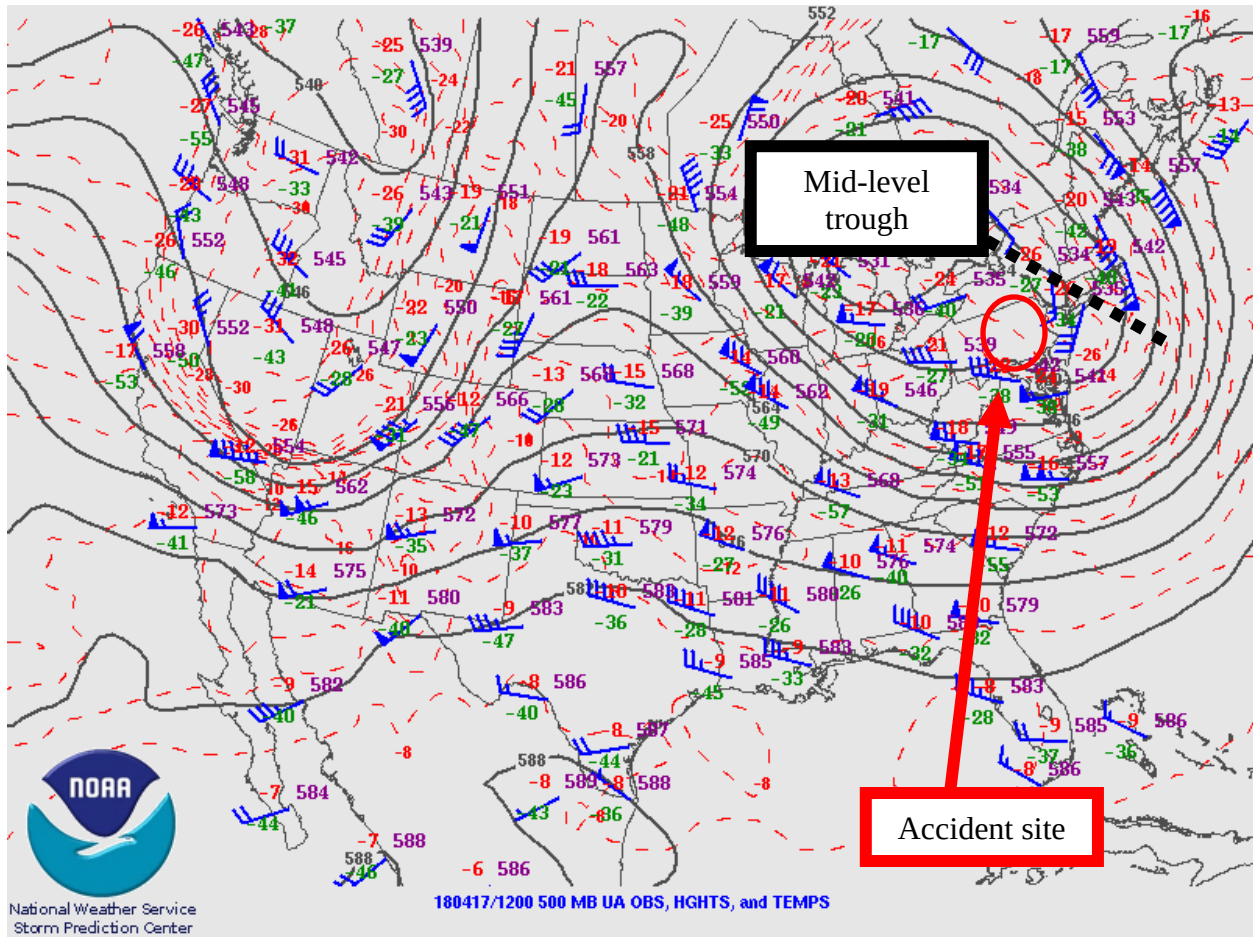


Figure 5 – 500-hPa Constant Pressure Chart for 0800 EDT

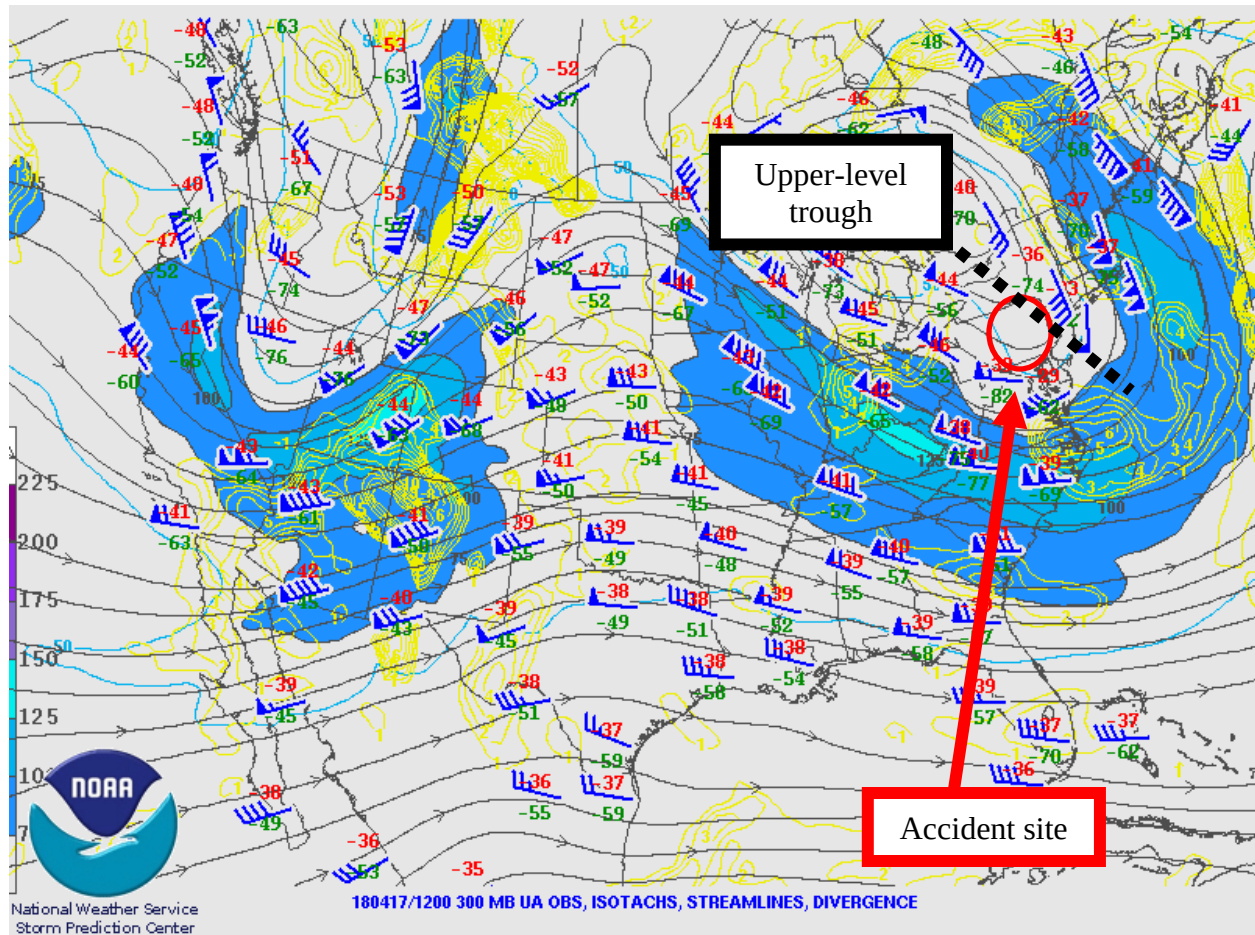


Figure 6 – 300-hPa Constant Pressure Chart for 0800 EDT

2.0 Surface Observations

The departure and diversion airports were documented using official Meteorological Aerodrome Reports (METARs) and Specials (SPECIs). The following observations were taken from standard code and are provided in plain language following the raw coded observations.

LaGuardia Airport (KLGA) was the departure airport located 4 miles east of New York City, New York. KLGA had an Automated Surface Observing System (ASOS⁴) whose reports were supplemented by a certified human observer. KLGA was located at an elevation of 21 feet (ft) and had an 13° westerly magnetic variation⁵. The following observations were taken and disseminated during the times surrounding the accident:⁶

⁴ ASOS – Automated Surface Observing System is equipped with meteorological instruments to observe and report wind, visibility, ceiling, temperature, dewpoint, altimeter, and barometric pressure.

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

⁶ 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 2.0 next to the METARs are provided for quick reference between UTC and local times around the accident time.

[0651 EDT] METAR KLGA 171051Z 28013KT 10SM FEW026 FEW032 BKN065 OVC250
06/M01 A2964 RMK AO2 SLP037 T00561011=

[0751 EDT] METAR KLGA 171151Z 29014KT 10SM FEW028 OVC065 06/M01 A2967
RMK AO2 SLP045 60000 70162 T00561011 10083 20056 53015=

[0851 EDT] METAR KLGA 171251Z 27012G21KT 10SM FEW028 OVC075 06/M02 A2967
RMK AO2 SLP048 T00611017=

**[0951 EDT] METAR KLGA 171351Z 27014G20KT 10SM BKN038 OVC080 07/M02 A2968
RMK AO2 SLP050 T00671022=**

Takeoff from KLGA 1043 EDT

**[1051 EDT] METAR KLGA 171451Z 29014G21KT 10SM BKN043 BKN080 08/M03 A2966
RMK AO2 SLP043 T00781028 58002=**

ACCIDENT TIME 1103 EDT

**[1151 EDT] METAR KLGA 171551Z 30014G20KT 10SM BKN043 BKN050 OVC080
08/M03 A2965 RMK AO2 SLP039 T00831028=**

[1251 EDT] METAR KLGA 171651Z 27015G23KT 10SM BKN047 OVC080 08/M03 A2964
RMK AO2 SLP037 T00831033=

[1351 EDT] METAR KLGA 171751Z 26015G20KT 10SM BKN046 BKN085 08/M03 A2963
RMK AO2 SLP033 T00831033 10083 20056 57009=

KLGA weather observation at 0951 EDT, wind from 270° at 14 knots with gusts to 20 knots, 10 miles visibility or greater, broken ceiling at 3,800 ft (ft) above ground level (agl), overcast skies at 8,000 ft agl, temperature of 7° C, dew point temperature of -2° C, and an altimeter setting of 29.68 inches of mercury. Remarks: automated station with a precipitation discriminator, sea level pressure 1005.0 hPa, temperature 6.7° C, dew point temperature -2.2° C.

KLGA weather observation at 1051 EDT, wind from 290° at 14 knots with gusts to 21 knots, 10 miles visibility or greater, broken ceiling at 4,300 ft agl, broken skies at 8,000 ft agl, temperature of 8° C, dew point temperature of -3° C, and an altimeter setting of 29.66 inches of mercury. Remarks: automated station with a precipitation discriminator, sea level pressure 1004.3 hPa, temperature 7.8° C, dew point temperature -2.8° C, 3-hourly pressure decrease of 0.2 hPa.

KLGA weather observation at 1151 EDT, wind from 300° at 14 knots with gusts to 20 knots, 10 miles visibility or greater, broken ceiling at 4,300 ft agl, broken skies at 5,000 ft agl, overcast skies at 8,000 ft agl, temperature of 8° C, dew point temperature of -3° C, and an altimeter setting of 29.65 inches of mercury. Remarks: automated station with a precipitation discriminator, sea level pressure 1003.9 hPa, temperature 8.3° C, dew point temperature -2.8° C.

Philadelphia International Airport (KPHL) was the airport the accident airplane diverted to after the accident occurred, with KPHL located 5 miles southwest of Philadelphia, Pennsylvania. KPHL had an ASOS whose reports were supplemented by a certified human observer. KPHL was located at an elevation of 36 ft and had an 12° westerly magnetic variation.⁷ The following observations were taken and disseminated during the times surrounding the accident:

[0754 EDT] METAR KPHL 171154Z 27011KT 10SM BKN045 BKN080 05/M03 A2975
RMK AO2 SLP074 70029 T00501033 10067 20044 53011 \$=

[0854 EDT] METAR KPHL 171254Z 28015G20KT 10SM BKN043 BKN075 06/M03 A2975
RMK AO2 SLP075 T00561028=

[0954 EDT] METAR KPHL 171354Z 28015G21KT 10SM BKN043 BKN075 07/M04 A2975
RMK AO2 SLP074 T00671039=

***[1054 EDT] METAR KPHL 171454Z 29018G27KT 10SM BKN048 BKN080 07/M04 A2975
RMK AO2 PK WND 27028/1442 SLP072 T00721044 58002=***

ACCIDENT TIME 1103 EDT

Landed at KPHL 1121 EDT

***[1154 EDT] METAR KPHL 171554Z 27016G21KT 10SM BKN049 OVC080 07/M04 A2973
RMK AO2 PK WND 27029/1517 SLP069 T00721039=***

[1254 EDT] METAR KPHL 171654Z 27018G24KT 10SM BKN047 OVC080 07/M04 A2973
RMK AO2 PK WND 27031/1615 SLP068 T00671039=

[1354 EDT] METAR KPHL 171754Z 26016KT 10SM BKN049 OVC060 07/M04 A2973
RMK AO2 SLP067 T00671039 10078 20050 56005=

[1454 EDT] METAR KPHL 171854Z 27013G21KT 10SM BKN048 06/M04 A2972 RMK
AO2 PK WND 25027/1837 SLP064 T00611044=

KPHL weather observation at 1054 EDT, wind from 290° at 18 knots with gusts to 27 knots, 10 miles visibility or greater, broken ceiling at 4,800 ft agl, broken skies at 8,000 ft agl, temperature of 7° C, dew point temperature of -4° C, and an altimeter setting of 29.75 inches of mercury. Remarks: automated station with a precipitation discriminator, peak wind from 270° at 28 knots at 1042 EDT, sea level pressure 1007.2 hPa, temperature 7.2° C, dew point temperature -4.4° C, 3-hourly pressure decrease of 0.2 hPa.

⁷ Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from sectional chart provided on <https://www.airnav.com/airport/KPHL>

KPHL weather observation at 1154 EDT, wind from 270° at 16 knots with gusts to 21 knots, 10 miles visibility or greater, broken ceiling at 4,900 ft agl, overcast skies at 8,000 ft agl, temperature of 7° C, dew point temperature of -4° C, and an altimeter setting of 29.73 inches of mercury. Remarks: automated station with a precipitation discriminator, peak wind from 270° at 29 knots at 1117 EDT, sea level pressure 1006.9 hPa, temperature 7.2° C, dew point temperature -3.9° C.

The observations from KLGA and KPHL surrounding the accident time indicated VFR⁸ conditions prevailed with a gusty surface wind from the west at the surface.

3.0 Upper Air Data

A High-Resolution Rapid Refresh (HRRR)⁹ model sounding was created for the accident site for 1100 EDT with station elevation of 453 ft. The 1100 EDT HRRR sounding was plotted on a standard Skew-T Log P diagram¹⁰ with the derived stability parameters included in figure 7 (with data from the surface to 200-hPa, or around 39,000 ft msl.) This data was analyzed using the RAOB¹¹ software package. The sounding depicted the lifted condensation level (LCL)¹² and the level of free convection (LFC)¹³ at 3,412 ft msl (2,959 ft agl) with the convective condensation level (CCL)¹⁴ at 4,011 ft msl (3,558 ft agl). The freezing level was located at 1,826 ft msl. The precipitable water value was 0.40 inches. The tropopause was located at 30,357 ft msl.

⁸ Visual Flight Rules – Refers to the general weather conditions pilots can expect at the surface. VFR criteria means a ceiling greater than 3,000 ft agl and greater than 6 miles visibility.

⁹ The HRRR is a NOAA real-time three-kilometer resolution, hourly-updated, cloud-resolving, convection-allowing atmospheric model, initialized by three-kilometer grids with three-kilometer radar assimilation. Radar data is assimilated in the HRRR every 15 minutes over a one-hour period.

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.

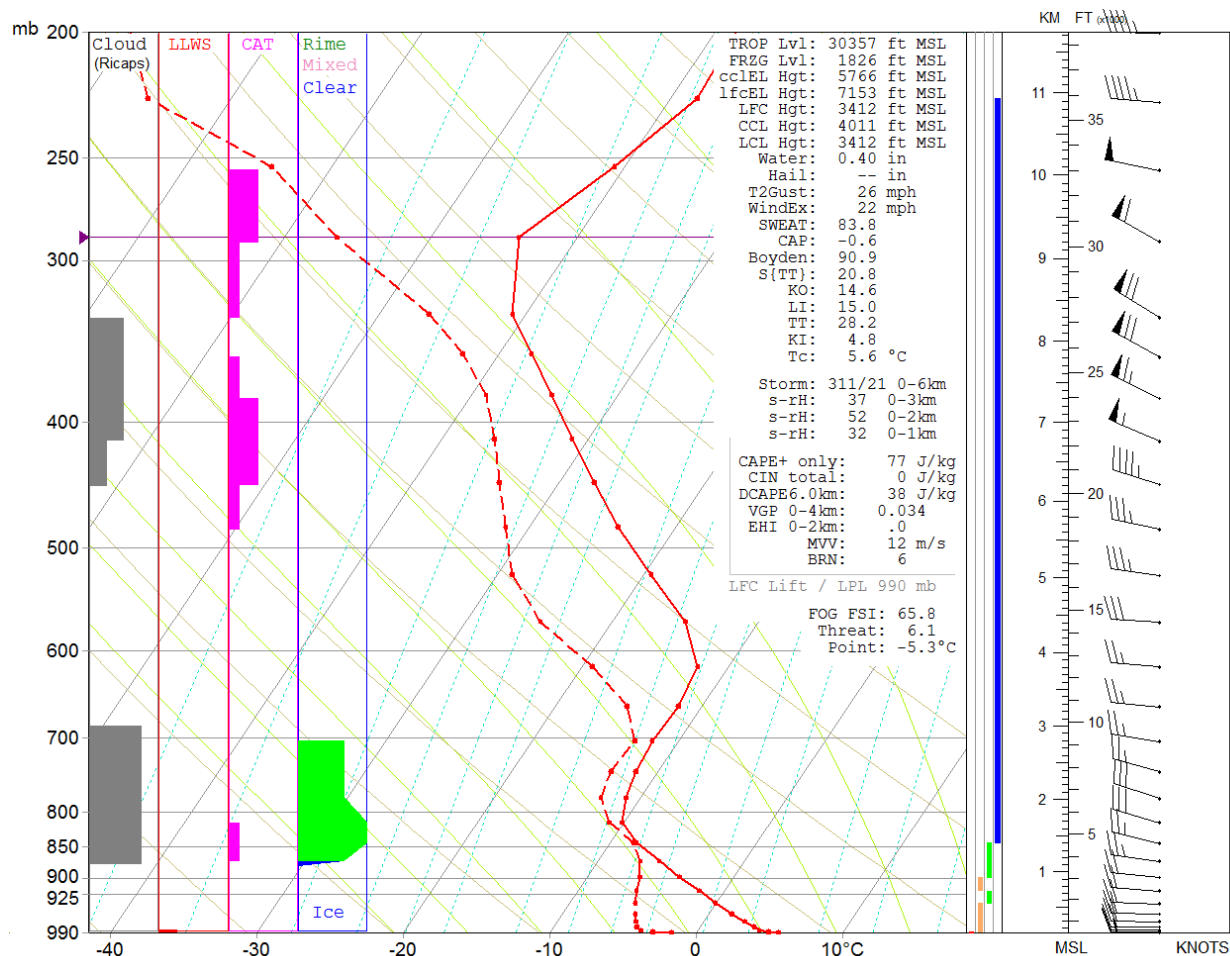


Figure 7 – 1100 EDT HRRR sounding

The 1100 EDT HRRR sounding indicated a conditionally unstable to unstable environment from the surface through 5,000 ft followed by a stable environment from 5,000 ft through 36,000 ft. RAOB identified the possibility of clouds between 4,000 ft and 10,000 ft and the possibility of clouds again from 21,000 ft through 27,000 ft. Moderate or greater rime icing was indicated by RAOB between 3,000 and 9,000 ft msl.

The 1100 EDT HRRR sounding wind profile indicated a surface wind from 270° at 14 knots with the wind remaining westerly through 39,000 ft. The wind speed was as high as 30 knots between the surface and 10,000 ft. Above 10,000 ft the wind remained westerly with a peak wind of 72 knots at 27,000 ft. Around 32,000 ft msl the wind was from 282° at 52 knots. RAOB indicated a small chance of light 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 layer between the surface and 33,000 ft, including a moderate probability of light to moderate clear air turbulence around 32,000 ft.

4.0 Satellite Data

The Geostationary Operational Environmental Satellite number 16 (GOES-16) imagery surrounding the period was obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System software. Visible and infrared imagery (GOES-16 bands 2 and 13) at wavelengths of 0.64 microns (μm) and 10.3 μm , respectively from 0900 EDT through 1300 EDT at approximately 15-minute intervals were reviewed, and the closest images to the time of the accident are documented here.

Figures 8 and 9 present the GOES-16 visible imagery from 1100 and 1107 EDT at 1X magnification with the accident site highlighted with a red square. Inspection of the visible imagery indicated cloud cover over the accident site with the cloud cover moving from west to east. Figure 10 presents the GOES-16 infrared imagery from 1102 EDT at 4X 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 over central Pennsylvania. Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 1100 EDT HRRR sounding, the approximate cloud-top heights over the accident site were 16,000 ft at 1102 EDT. It should be noted these figures have not been corrected for any parallax error.

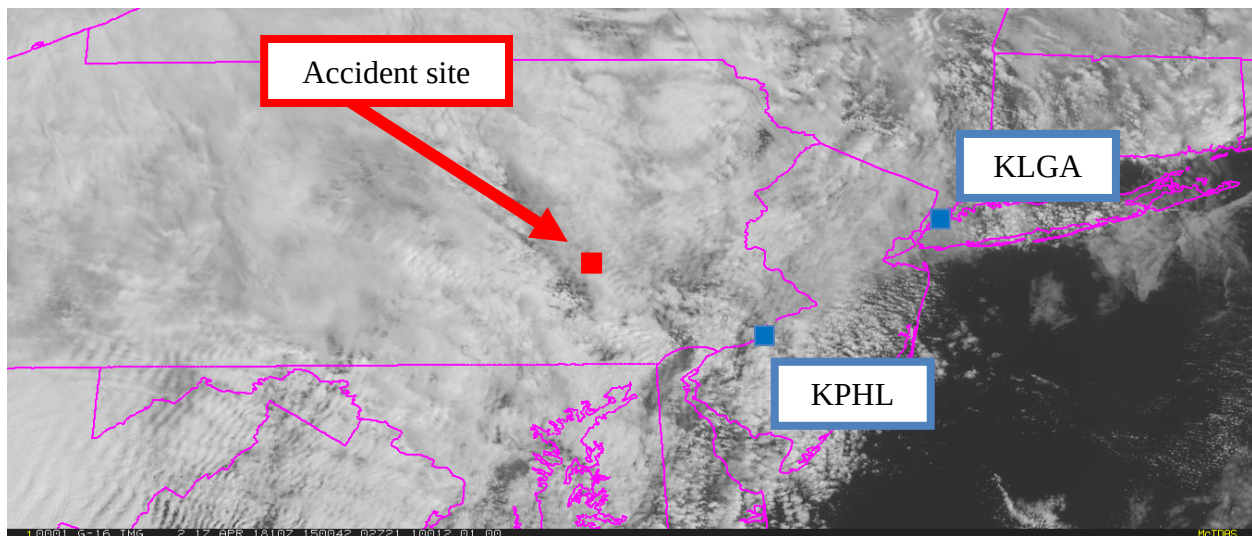


Figure 8 – GOES-16 visible image at 1100 EDT

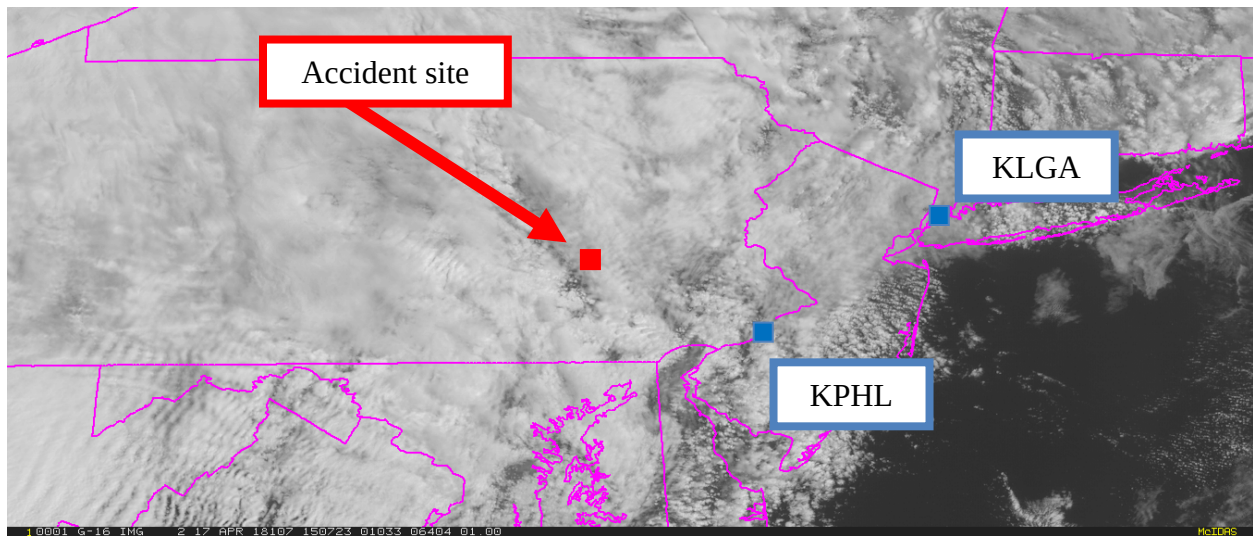


Figure 9 – GOES-16 visible image at 1107 EDT

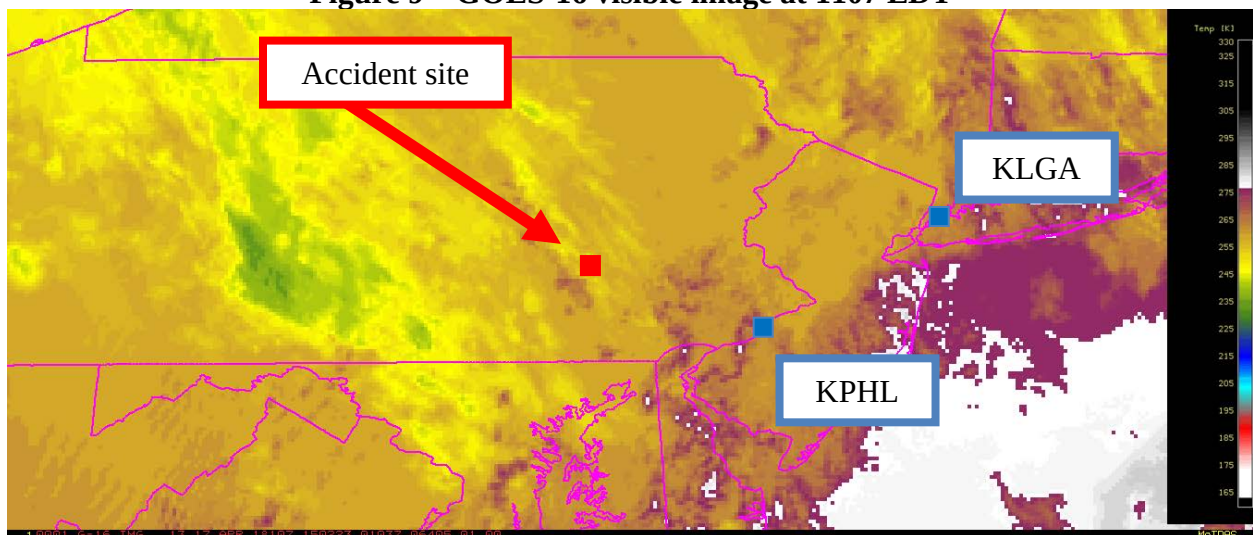


Figure 10 – GOES-16 infrared image at 1102 EDT

5.0 Radar Imagery Information

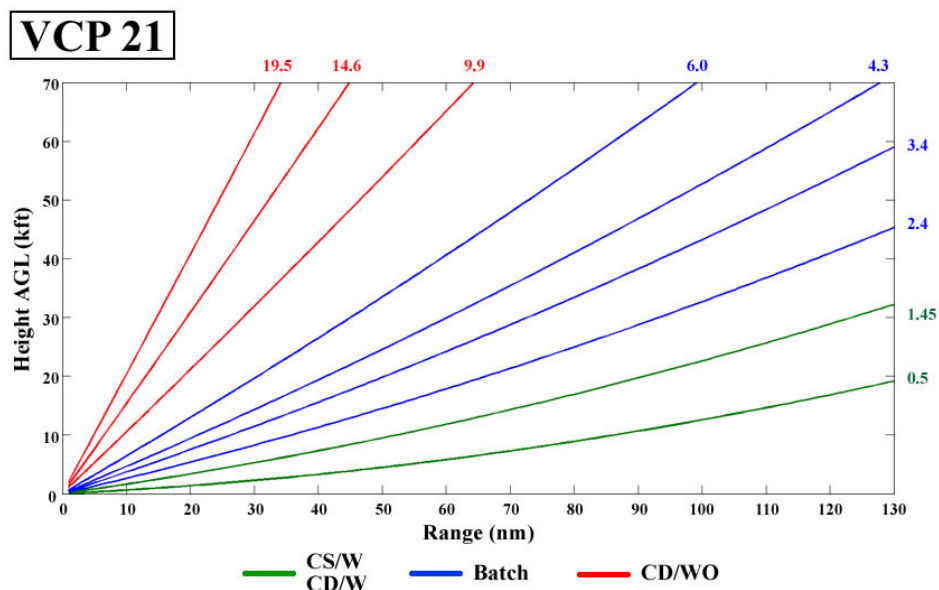
Both the NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)¹⁵ radars at State College, Pennsylvania, (KCCX) and Manchester, New Jersey, (KDIX) detected non-precipitation targets after the accident time. The KCCX radar was located 85 miles west-northwest of the accident site with an antenna height of 2,486 ft. The KDIX radar was located 89 miles east-southeast of the accident site with the antenna height of 231 ft. Level II and 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.

¹⁵ 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.

5.1 Volume Scan Strategy

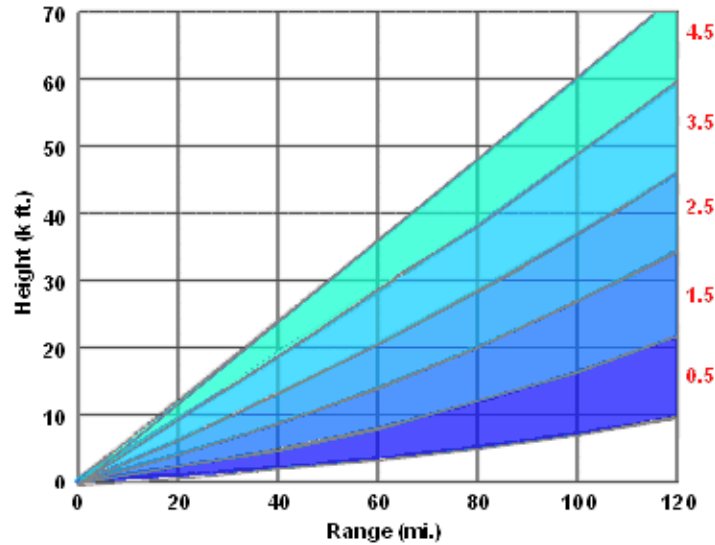
The WSR-88D is a computer-controlled radar system, which automatically creates a complete series of specific scans in a specific sequence known as a volume scan. Individual elevation scans are immediately available on the WSR-88D's Principle Users Processor (PUP). Products that require data from multiple 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 two common scanning strategies. The most common is where the radar makes 9 elevation scans from 0.5° to 19.5° every six minutes. This particular scanning strategy is documented as volume coverage pattern 21 (VCP-21). 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 KDIX WSR-88D radar was operating in precipitation mode (Mode A, VCP-21). 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-21 Precipitation Mode Scan Strategy

During the period surrounding the accident, the KCCX WSR-88D radar was operating in 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 Precipitation Mode Scan Strategy

5.2 Beam Height Calculation

Assuming standard refraction¹⁶ of the WSR-88D radar beam, and considering a beamwidth¹⁷ 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
KCCX 0.5°	12,240 ft	8,050 ft	16,430 ft
KCCX 1.5°	21,220 ft	17,030 ft	25,410 ft
KCCX 2.5°	30,200 ft	26,010 ft	34,390 ft
KDIX 0.5°	10,690 ft	6,300 ft	15,080 ft
KDIX 1.4°	20,100 ft	15,710 ft	24,490 ft

Based on the radar height calculations, the KCCX and KDIX elevation scan depicted the conditions between 6,300 ft and 34,390 ft msl over the accident site.

¹⁶ Standard Refraction in the atmosphere is when the temperature and humidity distributions are approximately average, and values set at the standard atmosphere.

¹⁷ Beamwidth - the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum value.

5.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors¹⁸ it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in decibels (dBZ¹⁹), and is a general measure of echo intensity. FAA Advisory Circular AC 00-24C²⁰, “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.

5.4 Base Reflectivity and Lightning Data

Figures 11 and 12 present the KCCX WSR-88D base reflectivity images for the 1.4° and 0.5° elevation scans initiated at 1106 and 1116 EDT, respectively, with a resolution of 0.5° X 250 m. Between 1106 and 1116 EDT, a cluster of non-precipitation echoes between -5 and 15 dBZ appeared just east-southeast of the accident site with continuing movement eastward moving with the environmental wind. These echoes are not consistent with precipitation targets (sections 5.5 and 5.6).

There were no lightning strikes in the vicinity of the accident flight around the accident time.²¹

¹⁸ Hydrometeors are any product of condensation or sublimation of atmospheric water vapor, whether formed in the free atmosphere or at the earth’s surface; also, any water particles blown by the wind from the earth’s surface. Hydrometeors are classified as; (a) Liquid or solid water particles suspended in the air: cloud, water droplets, mist or fog. (b) Liquid precipitation: drizzle and rain. (c) Freezing precipitation: freezing drizzle and freezing rain. (d) Solid (frozen) precipitation: ice pellets, hail, snow, snow pellets, and ice crystals. (e) Falling particles that evaporate before reaching the ground: virga. (f) Liquid or solid water particles lifted by the wind from the earth’s surface: drifting snow, blowing snow, blowing spray. (g) Liquid or solid deposits on exposed objects: dew, frost, rime, and glazed ice.

¹⁹ 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.

²⁰

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

²¹ A review of data from the Earth Networks Total Lightning Network was performed.

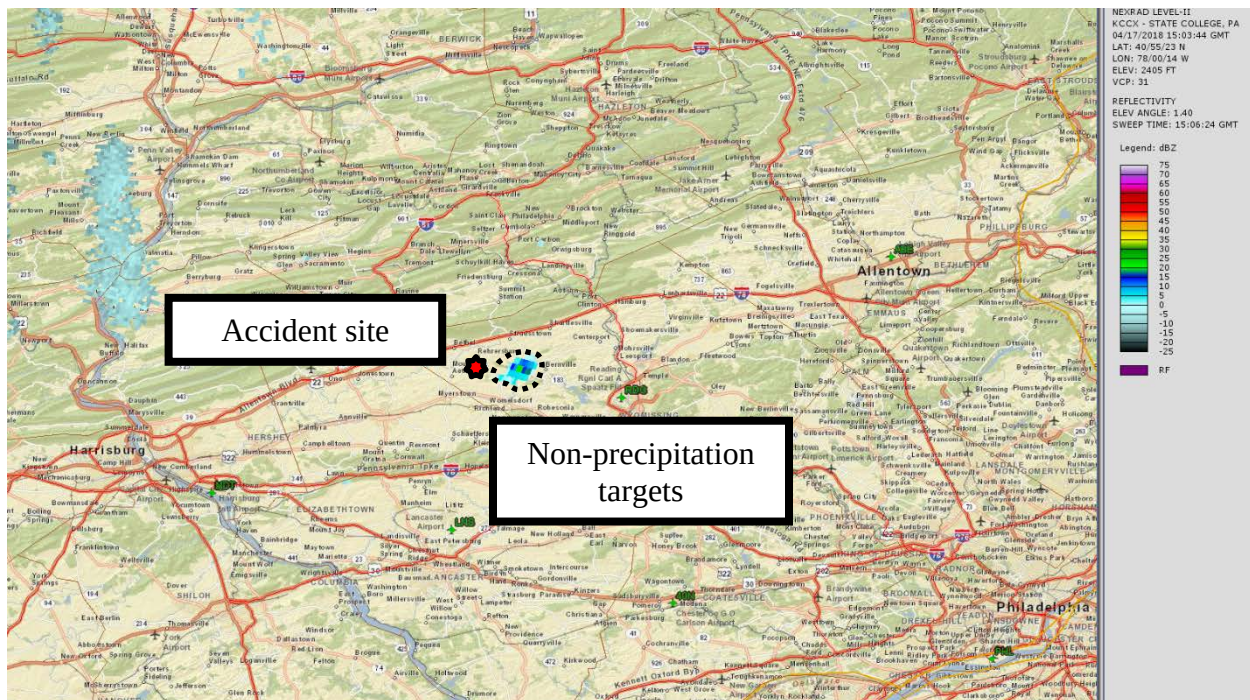


Figure 11 – KCCX WSR-88D reflectivity for the 1.4° elevation scan initiated at 1106 EDT

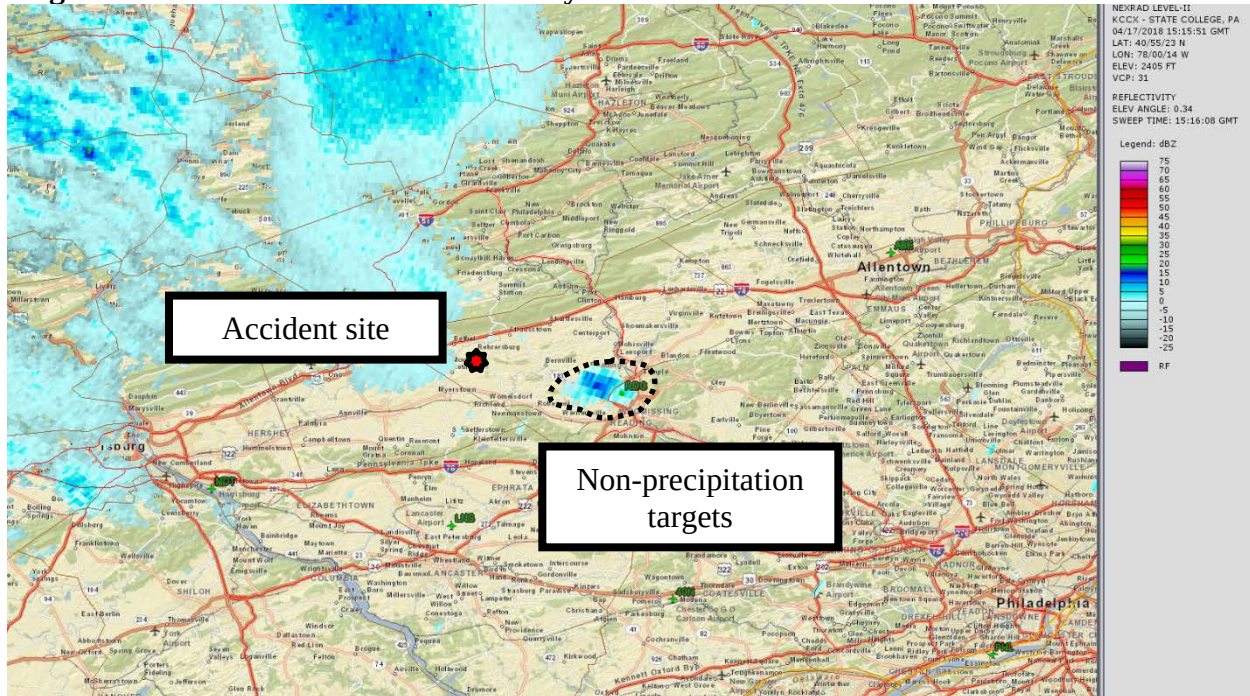


Figure 12 – KCCX WSR-88D reflectivity for the 0.5° elevation scan initiated at 1116 EDT

5.5 Zdr, CC, KDP, and HC²²

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 return²³. 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 horizontal²⁴. 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 horizontal²⁵.

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 1²⁶. 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.

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.

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.

²² Definitions for Zdr, CC, KDP, and HC adapted from training material from the NWS WDTD.

²³ A positive Zdr means that the dominant hydrometeors within the volume are larger in the horizontal than vertical (i.e. rain drops).

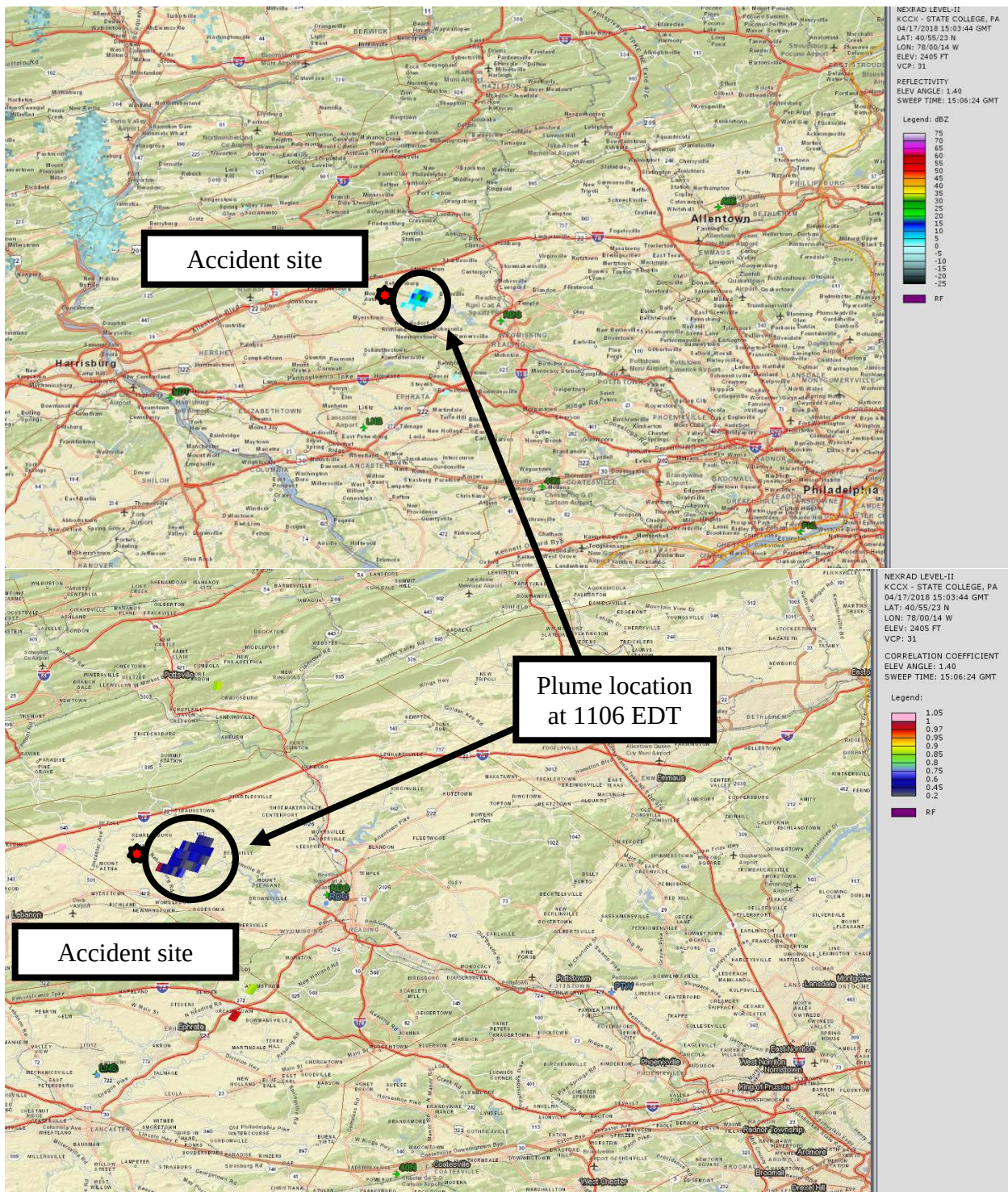
²⁴ A negative Zdr correlates to vertically oriented hydrometeors, i.e. vertically oriented crystals or conical graupel.

²⁵ A near zero Zdr is often an indication of hail or spherical rain drops.

²⁶ CC values greater than 1 indicate an untrustworthy signal due to low signal-to-noise ratio in areas of weak reflectivity.

5.6 Dual-Pol Imagery

Figure 13 presents the KCCX WSR-88D base reflectivity and CC values for the 1.5° elevation scans initiated at 1106 EDT with a resolution of 1.0° X 1 km. Figure 13 depicted light non-meteorological echoes to the east of the accident site located downstream as discussed and shown in time sequence in attachment 1 from both KCCX and KDIX radars. Within the non-meteorological echoes the dBZ values were observed between -5 and 15 dBZ and CC values at or below 0.45. Figures 14, 15, and 16, showed the continued movement of the non-meteorological echoes east and southeast of the accident site from 1108 through 1127 EDT from both KCCX and KDIX. These values in the dual-pol data were consistent from the beginning of the targets being visible in the weather radar data around 1106 EDT through 1156 EDT (attachment 1), and indicated a very non-homogeneous group of targets with greater varying characteristics and sizes, which correlated to non-meteorological targets (section 5.5).



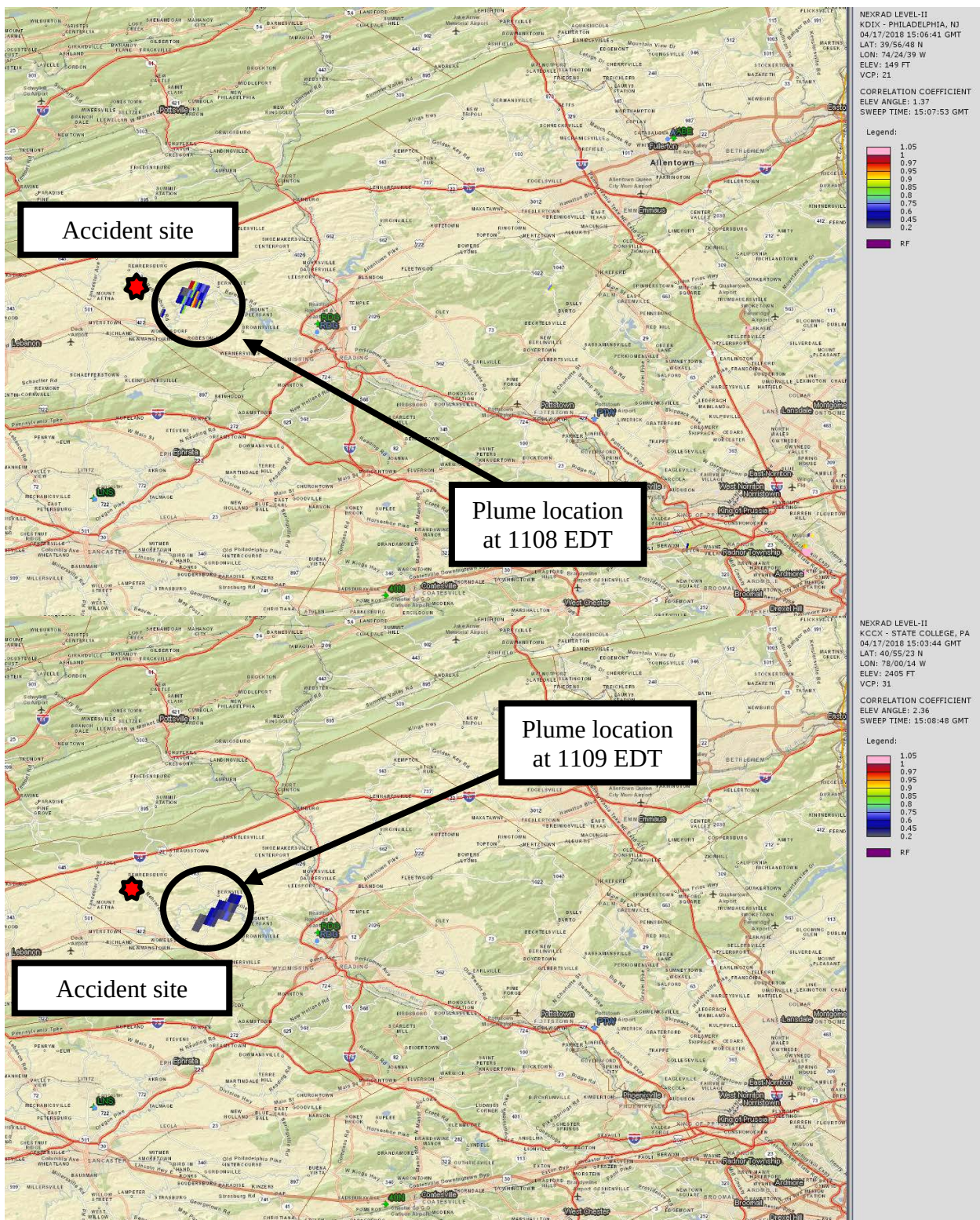


Figure 14 – (a) KDIX WSR-88D CC from the 1.4° elevation scan for 1108 EDT (b) KCCX WSR-88D CC from the 2.5° elevation scan for 1109 EDT

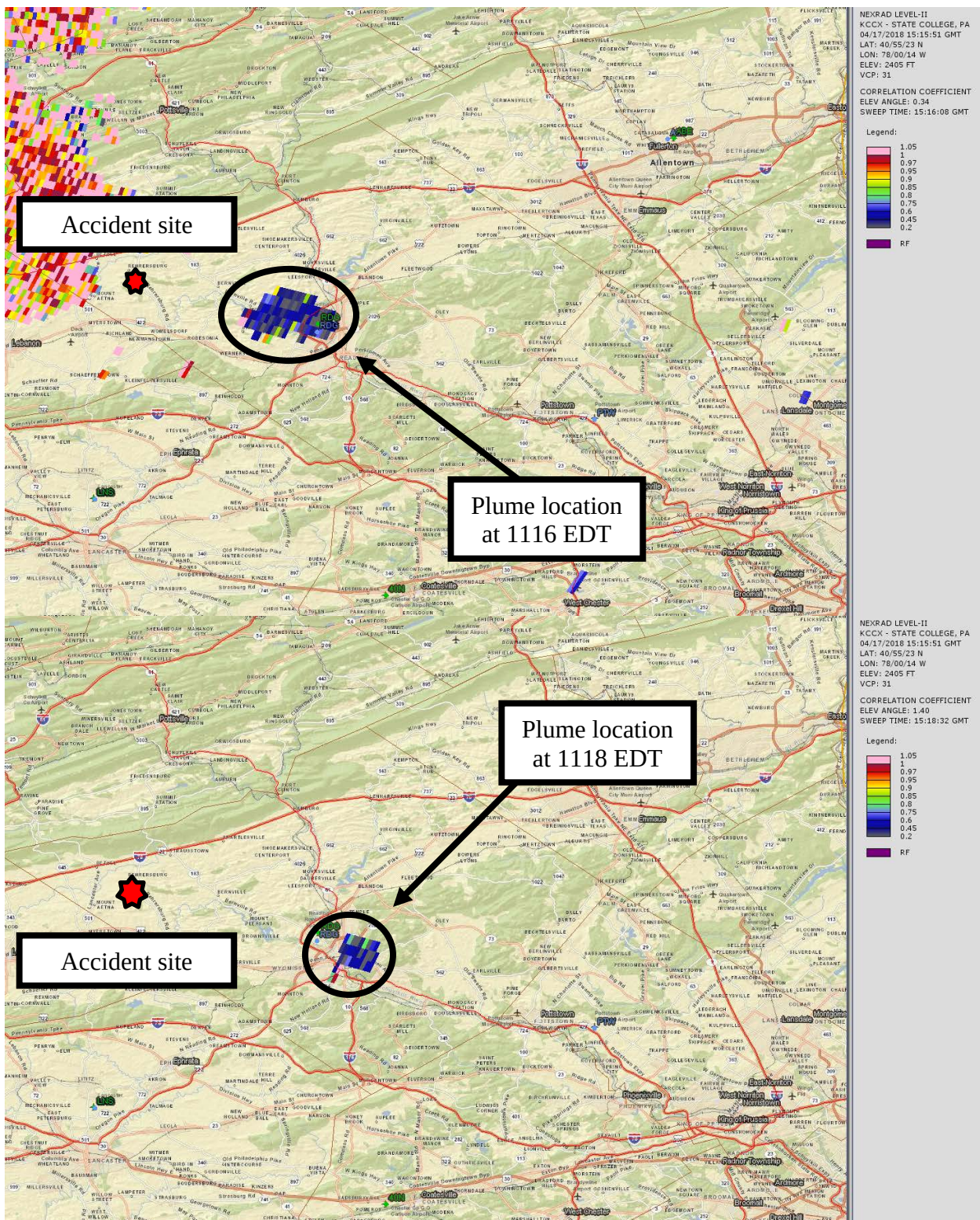


Figure 15 – (a) KCCX WSR-88D CC from the 0.5° elevation scan for 1116 EDT (b) KCCX WSR-88D CC from the 1.5° elevation scan for 1118 EDT

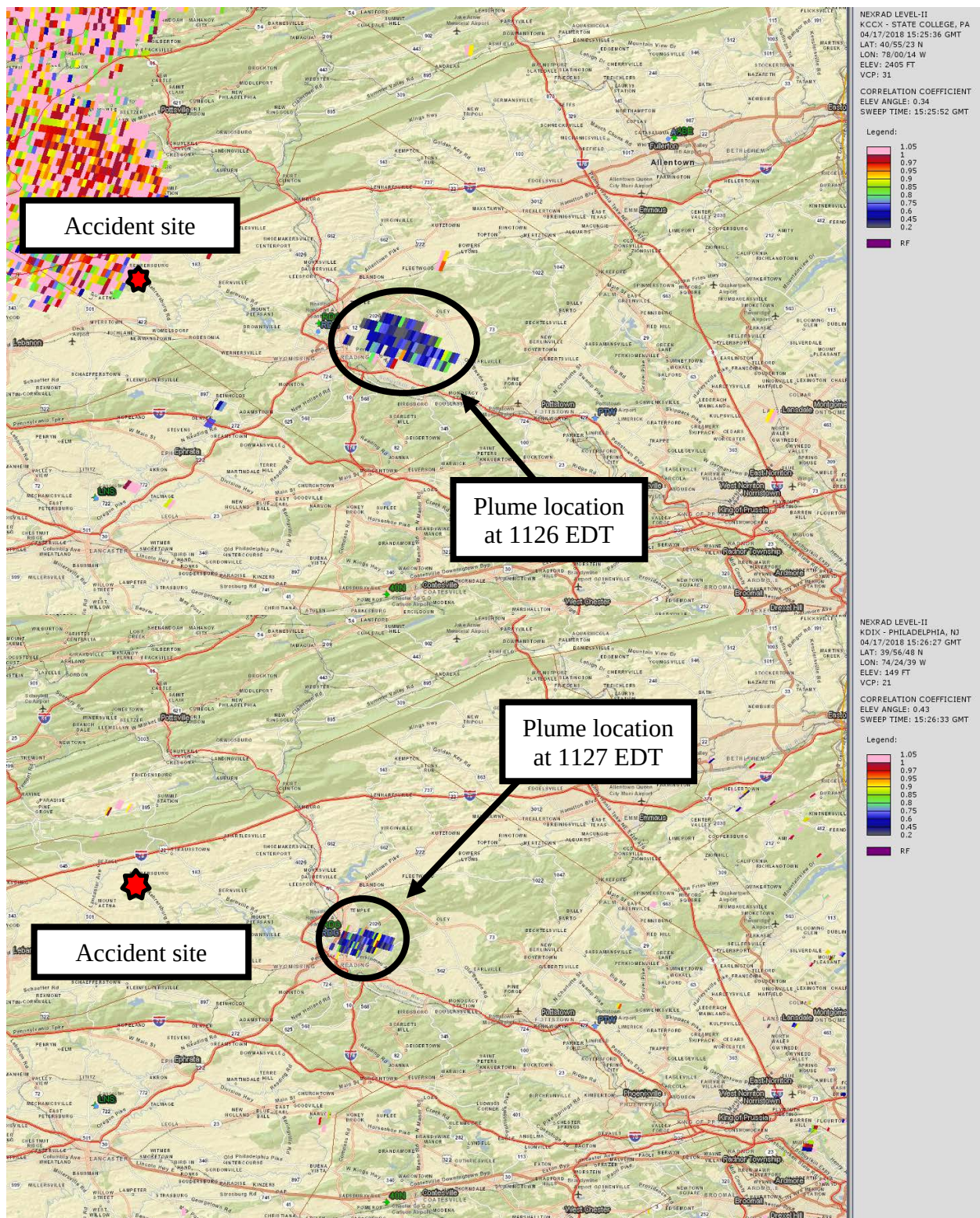


Figure 16 – (a) KCCX WSR-88D CC from the 0.5° elevation scan for 1126 EDT (b) KDIX WSR-88D CC from the 0.5° elevation scan for 1127 EDT

6.0 Pilot Reports²⁷

All pilot reports (PIREPs) within 100 miles of the accident site from about two hours prior to the accident time to about one hour after the accident time for altitudes above 10,000 ft are provided below in raw form:

UNV UA /OV PSB /TM 1337 /FL390 /TP LJ60 /TA M39 /WV 26952KT /TB NEG

ELM UA /OV SFK140010/TM 1344/FL120/TP SR22/TA M13/IC LGT RIME

LNS UA /OV LRP015020/TM 1345/FL130/TP G150/IC LGT MX

ARP UAL503 4043N 07632W 1509 F280 MS41 305/066KT TB SMTH SK ON TOP IC NONE RM B739 OV EMI023076 SMOOTH

The PIREPs decoded into plain language from standard code and abbreviations, and time converted to local were as follows:

Routine pilot report (UA) University Park Airport, Pennsylvania (UNV); Over - Philipsburg, Pennsylvania (PSB) VORTAC; Time – 0937 EDT (1337Z); Altitude – FL390; Type aircraft – Learjet 60; Temperature – -39° C; Wind – From 269° at 52 knots; Turbulence – Negative.

Routine pilot report (UA) Elmira/Corning Regional Airport, New York (ELM); Over - 10 miles from Stonyfork, Pennsylvania, (SFK) VORTAC on the 140° radial; Time – 0944 EDT (1344Z); Altitude – 12,000 ft; Type aircraft – Cirrus SR-22; Temperature – -13° C; Icing – Light rime.

Routine pilot report (UA) Lancaster Airport, Pennsylvania (LNS); Over 20 miles from Lancaster, Pennsylvania, (LRP) VORTAC on the 015° radial; Time – 0945 EDT (1345Z); Altitude – 13,000 ft; Type aircraft – Gulfstream G150; Icing – Light mixed.

Aircraft report (ARP); United Flight 503; Location at Latitude 40.43° N; Longitude 76.32° W; Time – 1109 EDT (1509Z); Altitude – FL280; Type aircraft – Boeing B737-900; Temperature – -41° C; Wind – From 305° at 66 knots; Turbulence – Smooth; Sky cover – On top; Icing – None; Remarks - 76 miles from Westminster (EMI) VORTAC, Maryland on the 023° radial.

7.0 SIGMET and CWSU Advisory

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

The New York (KZNY) Center Weather Service Unit (CWSU) issued no Center Weather Advisories (CWA) or Meteorological Impact Statements (MIS) valid for the accident site at the accident time.

²⁷ Only pilot reports with the WMO header UBPA**, UBMD**, UBNJ**, and UBNY** identifier were considered.

8.0 AIRMETs

There was only an Airmen's Meteorological Information (AIRMET) Tango advisory that was valid for the accident site at the accident time for above FL200. AIRMET Tango update 3 warned of moderate turbulence conditions between FL240 and FL410. The AIRMET was issued at 1045 EDT and valid until 1700 EDT. This advisory updated a previous AIRMET Tango update 2 that was previously issued for the region:

WAUS41 KPCI 171445

WA1T

-BOST WA 171445

AIRMET TANGO UPDT 3 FOR TURB AND STG SFC WNDZ VALID UNTIL 172100

.
AIRMET TURB...ME AND CSTL WTRS
FROM 70NW PQI TO 60NE PQI TO 100SSW YSJ TO 50W MLT TO 40SSE YQB
TO 70NW PQI
MOD TURB BLW FL180. CONDS ENDG 15-18Z.

.
AIRMET TURB...OH WV MD VA NC SC GA AND CSTL WTRS
FROM 50SE APE TO 20SSW SBY TO 90ESE ECG TO 80E ILM TO 60SSW ILM
TO ATL TO GQO TO HNV TO HNN TO 50W HNN TO 50SE APE
MOD TURB BLW 150. CONDS CONTG BYD 21Z THRU 03Z.

.
AIRMET TURB...ME NH VT MA AND CSTL WTRS
FROM 70NW PQI TO 60NE PQI TO 200SE ACK TO 180SSE ACK TO 20SSE
CON TO 20S YSC TO 70NW PQI
MOD TURB BTN FL180 AND FL410. CONDS ENDG 15-18Z.

.
**AIRMET TURB...ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA
NC SC GA AND CSTL WTRS
FROM 30NNE YOW TO 40E MPV TO 20SSE CON TO 180SSE ACK TO 160SE
SIE TO 190ESE ECG TO 130SE ILM TO 20SE SAV TO 30NW ATL TO GQO TO
HNV TO HNN TO CVG TO FWA TO 30SE ECK TO 30NNE YOW
MOD TURB BTN FL240 AND FL410. CONDS CONTG BYD 21Z THRU 03Z.**

.
OTLK VALID 2100-0300Z
AREA 1...TURB PA OH WV MD DC VA NC SC GA AND CSTL WTRS
BOUNDED BY 40WSW SLT-30E PSB-CSN-20SSW SBY-90ESE ECG-80E ILM-
60SSW ILM-30NE CHS-30SW ATL-GQO-HNV-HNN-50W HNN-40WSW SLT
MOD TURB BLW 140. CONDS CONTG THRU 03Z.

.
AREA 2...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 YSC-50ESE YSC-60SW YSJ-200SE ACK-160SE SIE-190ESE ECG-
130SE ILM-110SSE ILM-20ESE IRQ-40WSW VXV-HNV-HNN-CVG-FWA-30SE
ECK-YOW-YSC
MOD TURB BTN FL240 AND FL410. CONDS CONTG THRU 03Z.

.
AREA 3...STG SFC WNDZ MA RI NY NJ MD DE VA NC CSTL WTRS
BOUNDED BY 40S ACK-190S ACK-160SE SIE-190ESE ECG-140ESE ILM-
50ESE SIE-40S ACK
SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS DVLPG 00-03Z.
CONDS CONTG THRU 03Z.

....

WAUS41 KPCI 171145 AAA

WA1T

-BOST WA 171145 AMD

AIRMET TANGO UPDT 2 FOR TURB AND LLWS VALID UNTIL 171500

.
AIRMET TURB...ME NH VT MA RI CT NY AND CSTL WTRS
FROM 70NW PQI TO 60NE PQI TO 200SE ACK TO 210S ACK TO 40ENE MSS
TO YSC TO 70NW PQI
MOD TURB BTN FL180 AND FL410. CONDS CONTG BYD 15Z ENDG 15-18Z.

.
AIRMET TURB...ME NH AND CSTL WTRS
FROM 70NW PQI TO 60NE PQI TO 110SE BGR TO 60SSW BGR TO YSC TO
70NW PQI
MOD TURB BLW FL180. CONDS CONTG BYD 15Z ENDG 15-18Z.

.
AIRMET TURB...NY LO NJ PA OH LE WV MD DC DE VA NC SC GA
FROM 30E MSS TO 40NNE SAX TO 60SSE JST TO 50SW CSN TO 40W ECG TO
60SE RDU TO 60S ODF TO 20WNW ATL TO GQO TO HNV TO HNN TO 20N ERI
TO 50ENE YYY TO 30E MSS
MOD TURB BLW 140. CONDS CONTG BYD 15Z THRU 21Z.

.
**AIRMET TURB...MA CT NY LO NJ PA OH LE WV MD DC DE VA NC SC GA
AND CSTL WTRS...UPDT
FROM 70SSW MSS TO 90SSE HTO TO 160SE SIE TO 190ESE ECG TO 130SSE
ILM TO 30ESE IRQ TO GQO TO HNV TO HNN TO CVG TO FWA TO 30SE ECK
TO 70SSW MSS
MOD TURB BTN FL200 AND FL410. CONDS CONTG BYD 15Z THRU 21Z.**

.
LLWS POTENTIAL...ME NH AND CSTL WTRS
BOUNDED BY 70NW PQI-50NE PQI-110SE BGR-YSC-70NW PQI
LLWS EXP. CONDS ENDG 12-15Z.

.
OTLK VALID 1500-2100Z
AREA 1...TURB OH WV MD VA NC SC GA AND CSTL WTRS
BOUNDED BY 50SE APE-20SSW SBY-90ESE ECG-80E ILM-60SSW ILM-ATL-
20SSW GQO-HNV-HNN-50W HNN-50SE APE
MOD TURB BLW 150. CONDS CONTG THRU 21Z.

.
AREA 2...TURB ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA
NC SC AND CSTL WTRS...UPDT
BOUNDED BY 40SW MSS-140ENE ACK-200SE ACK-160SE SIE-190ESE ECG-
130SSE ILM-20ESE VXV-HNV-HNN-CVG-FWA-30SE ECK-40SW MSS
MOD TURB BTN FL200 AND FL410. CONDS CONTG THRU 21Z.

....

9.0 Winds and Temperature Aloft Forecast

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

FBUS31 KWN0 171400
FD1US1
DATA BASED ON 171200Z
VALID 171800Z FOR USE 1400-2100Z. TEMPS NEG ABV 24000

FT 3000 6000 9000 12000 18000 24000 30000 34000 39000

AVP 2618 2825-10 2723-12 2427-13 2630-21 **2850-30 296443 285142** 274141

The accident site was closest to the Wilkes-Barre/Scranton International Airport, Pennsylvania, forecast point (AVP). The 1000 EDT AVP forecast for use between 1000 EDT and 1700 EDT indicated a wind at 24,000 ft from 280° at 50 knots with a temperature of -30° C, a wind at 30,000 ft from 290° at 64 knots with a temperature of -43° C, and a wind at 34,000 ft from 280° at 51 knots with a temperature of -42° C.

10.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on April 17, 2018, indicated the following:

SUN	
Begin civil twilight	0555 EDT
Sunrise	0624 EDT
Accident time	1103 EDT²⁸
Sun transit	1304 EDT
Sunset	1946 EDT
End civil twilight	2014 EDT

E. LIST OF ATTACHMENTS

Attachment 1 – WSR-88D KCCX and KDIX CC data and animation from 1106 through 1156 EDT

Submitted by:

Paul Suffern
Senior Meteorologist

²⁸ Inserted accident time for reference and context.

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