



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

November 10, 2016

Weather Study

METEOROLOGY

CEN16LA281

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A. ACCIDENT

Location: Springfield, Ohio
Date: July 22, 2016
Time: 1040 eastern daylight time
1440 Coordinated Universal Time (UTC)
Airplane: Vans RV9, N807LK

B. METEOROLOGIST

Paul Suffern
Group Chairman
Operational Factors Division (AS-30)
National Transportation Safety Board

C. SUMMARY

On July 22, 2016, about 1040 eastern daylight time, an experimental amateur-built Vans RV9A airplane, N807LK, impacted terrain near Springfield, Ohio. The private rated pilot and one passenger were fatally injured and the airplane was destroyed. The airplane was registered to and operated by a private individual under the provisions of 14 *Code of Federal Regulations* Part 91 as a personal flight. Marginal visual meteorological conditions prevailed near the accident site and the airplane was receiving visual flight rules (VFR) flight following. The flight departed Tri-Cities Regional Airport (TRI), Bristol/Johnson/Kingsport, Tennessee, about 0850 eastern daylight time and was en route to Grosse Ile Municipal Airport (ONZ), Detroit/Grosse Ile, Michigan.

D. 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 the NTSB's Washington D.C. office and 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 July 22, 2016, and are based upon the 24-hour clock, where local time is -4 hours from UTC, and UTC=Z (unless otherwise noted). Directions are referenced to true north and distances in nautical miles. Heights are above mean sea level (msl) unless otherwise noted. Visibility is in statute miles and fractions of statute miles.

The accident site was located at latitude 39.87° N, longitude 83.69° W, at an approximate elevation of 1,069 feet.

E. FACTUAL INFORMATION

1.0 Synoptic Situation

The synoptic or large scale migratory weather systems influencing the area were documented using standard NWS charts issued by the National Center for Environmental Prediction and the Weather Prediction Center, located in College Park, Maryland. These are the base products used in describing synoptic weather features and in the creation of forecasts and warnings for the NWS. Reference to these charts can be found in the joint NWS and Federal Aviation Administration (FAA) Advisory Circular “Aviation Weather Services”, AC-0045G CHG 2.

1.1 Surface Analysis Chart

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 indicated the accident site was located in between two outflow boundaries¹ (section 17.0). One of the outflow boundaries was oriented southwest to northeast in northern Ohio and the other outflow boundary was oriented west to east in south Central Ohio, just south of the accident site (figure 1). These outflow boundaries along with the low- and mid-level troughs² (section 1.2) were likely acting as lifting mechanisms to aid in the formation of clouds, rain showers, and thunderstorms. The station models around the accident site at 1100 EDT depicted air temperatures in the low to mid 70’s degrees Fahrenheit (°F), with temperature-dew point spreads of 3° F or less, a southwest to west wind between 5 and 15 knots, cloudy skies, and thunderstorms.

¹ Outflow Boundary – A boundary, also known as a gust front, is a storm-scale or mesoscale boundary separating thunderstorm-cooled air (outflow) from the surrounding air; similar in effect to a cold front, with passage marked by a wind shift and usually a drop in temperature and a related pressure jump.

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

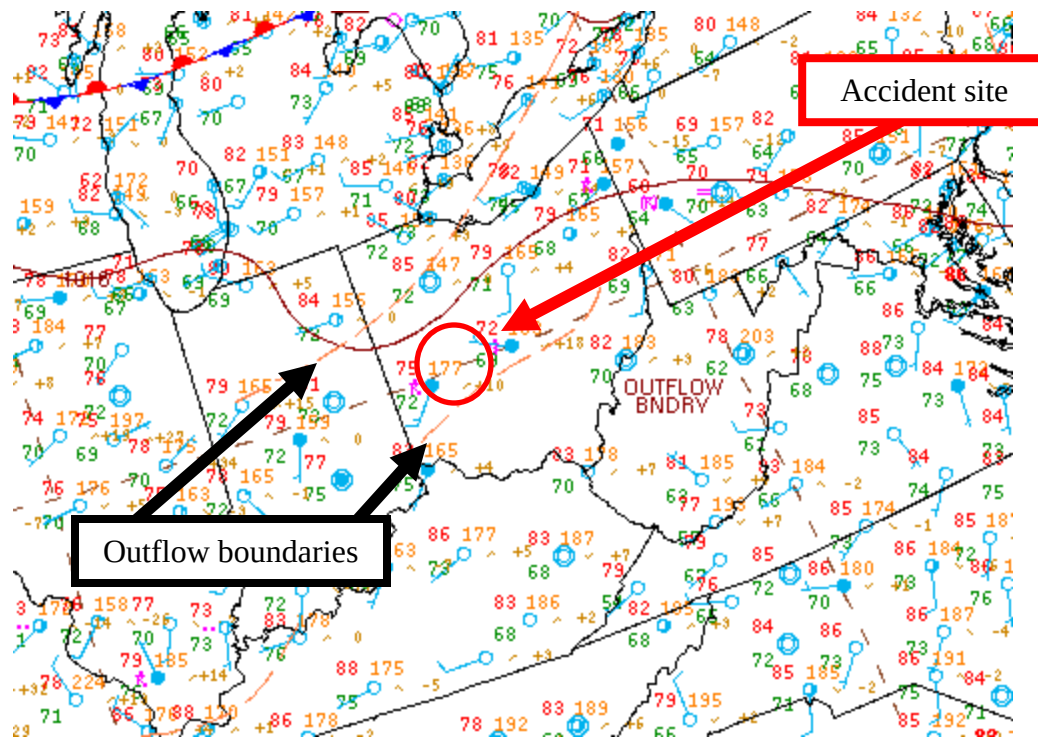


Figure 1 – NWS Surface Analysis Chart for 1100 EDT

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. The 925- and 850-hPa charts depicted low-level troughs just west of the accident site over Michigan and Illinois. Troughs typically act as lifting mechanisms where enhanced lift, gusty winds, fronts, clouds, and precipitation can occur. In addition, at 700-hPa, there was a mid-level trough west of the accident site (figure 4). There was sufficient low and mid-level moisture to allow for the formation of clouds and precipitation (section 4.0) around the accident site at the accident time. There was a southwest wind about 20 knots at 925-hPa (figure 2) with the wind becoming westerly by 700-hPa with a wind speed of 5 knots (figure 4). The 5-knot west wind at 700-hPa became a 20-knot northwest wind by 300-hPa (figure 6).

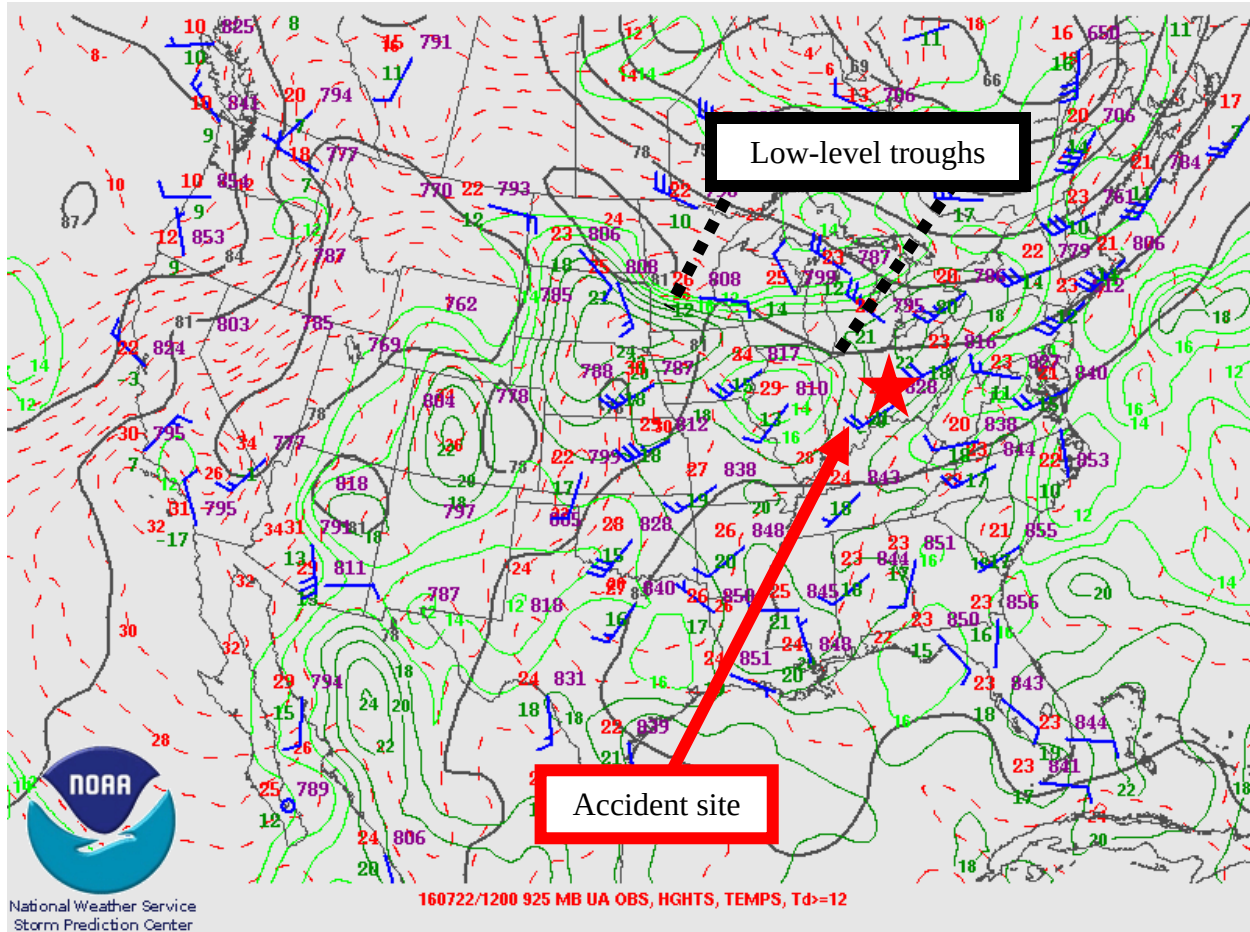


Figure 2 – 925-hPa Constant Pressure Chart for 0800 EDT

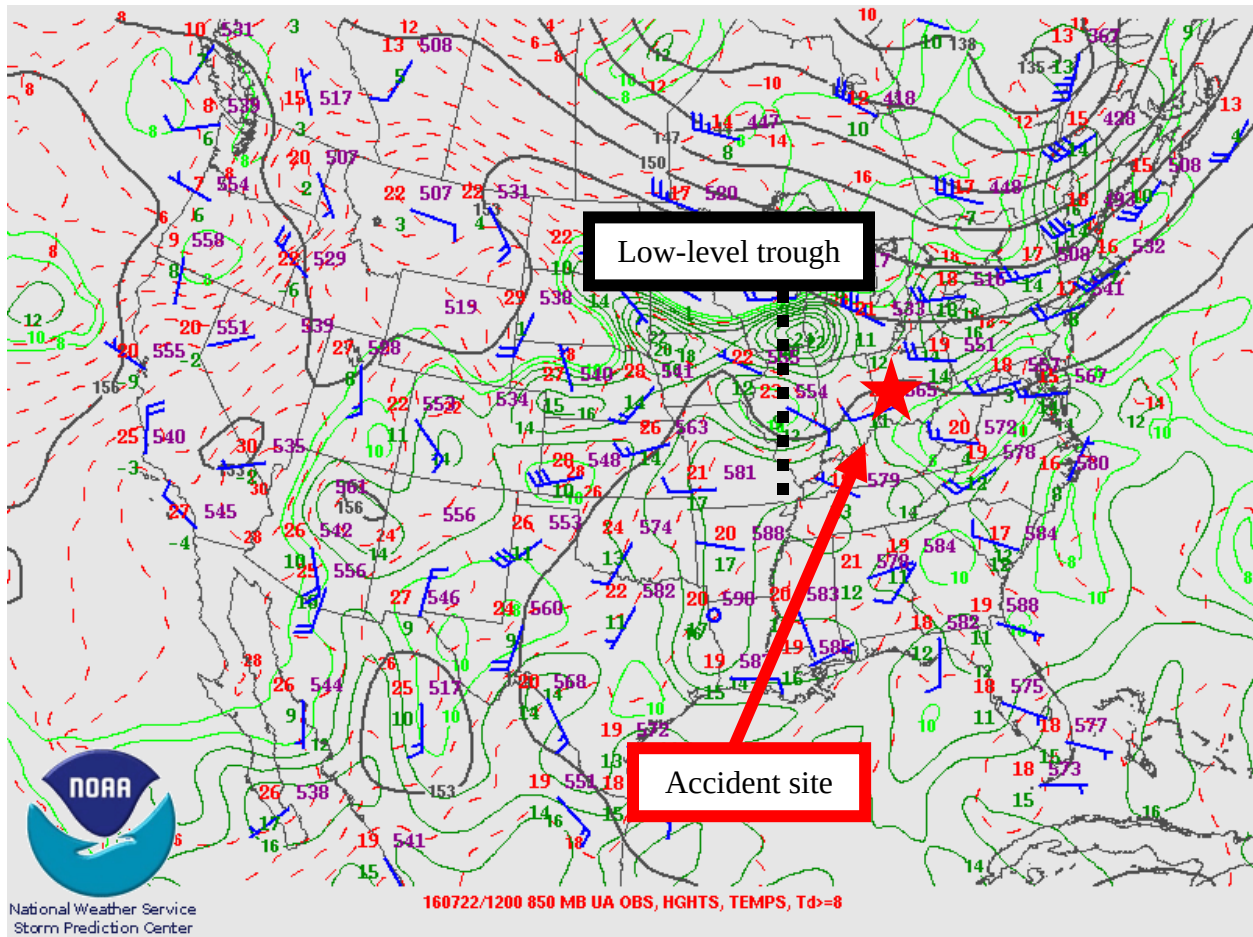


Figure 3 – 850-hPa Constant Pressure Chart for 0800 EDT

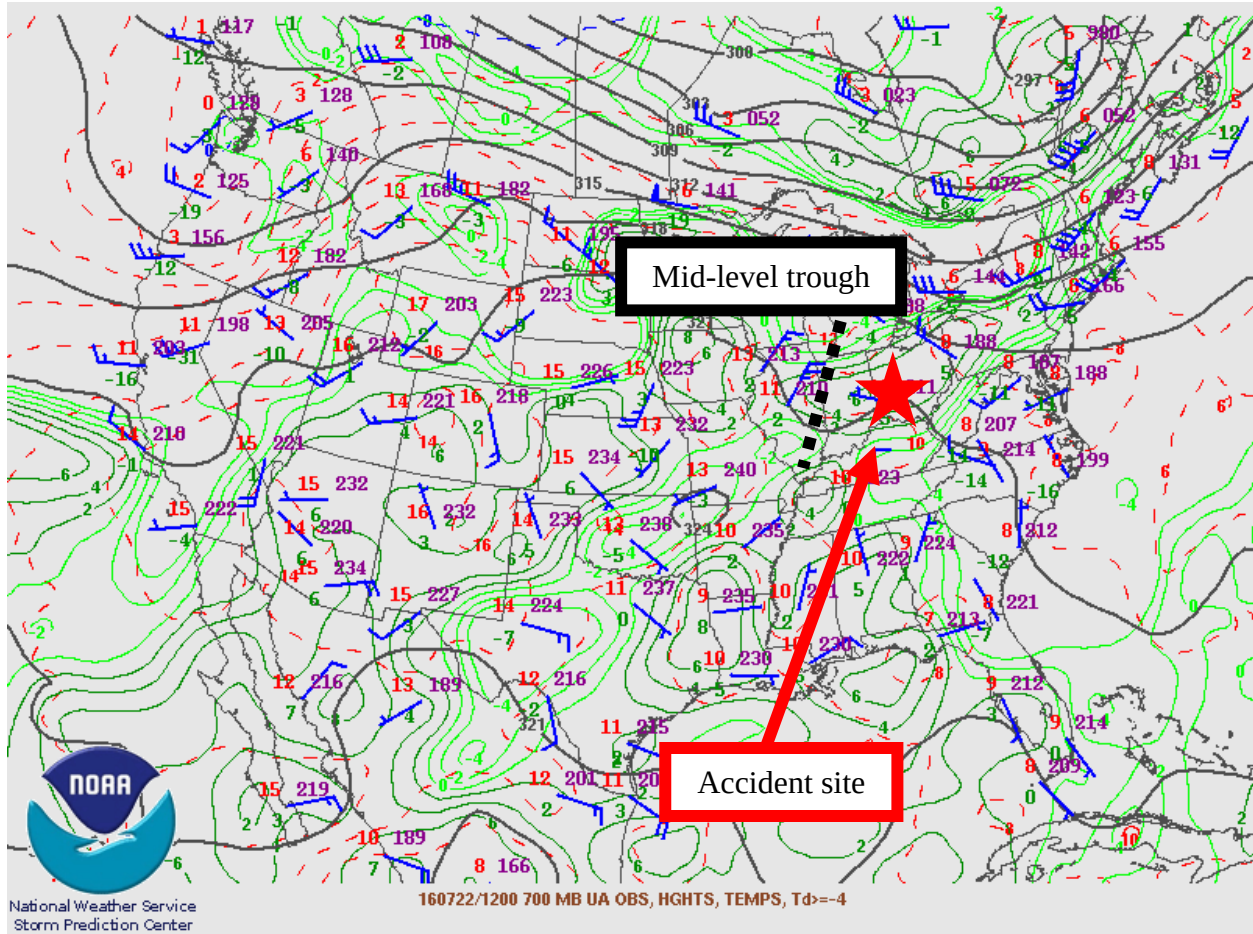


Figure 4 – 700-hPa Constant Pressure Chart for 0800 EDT

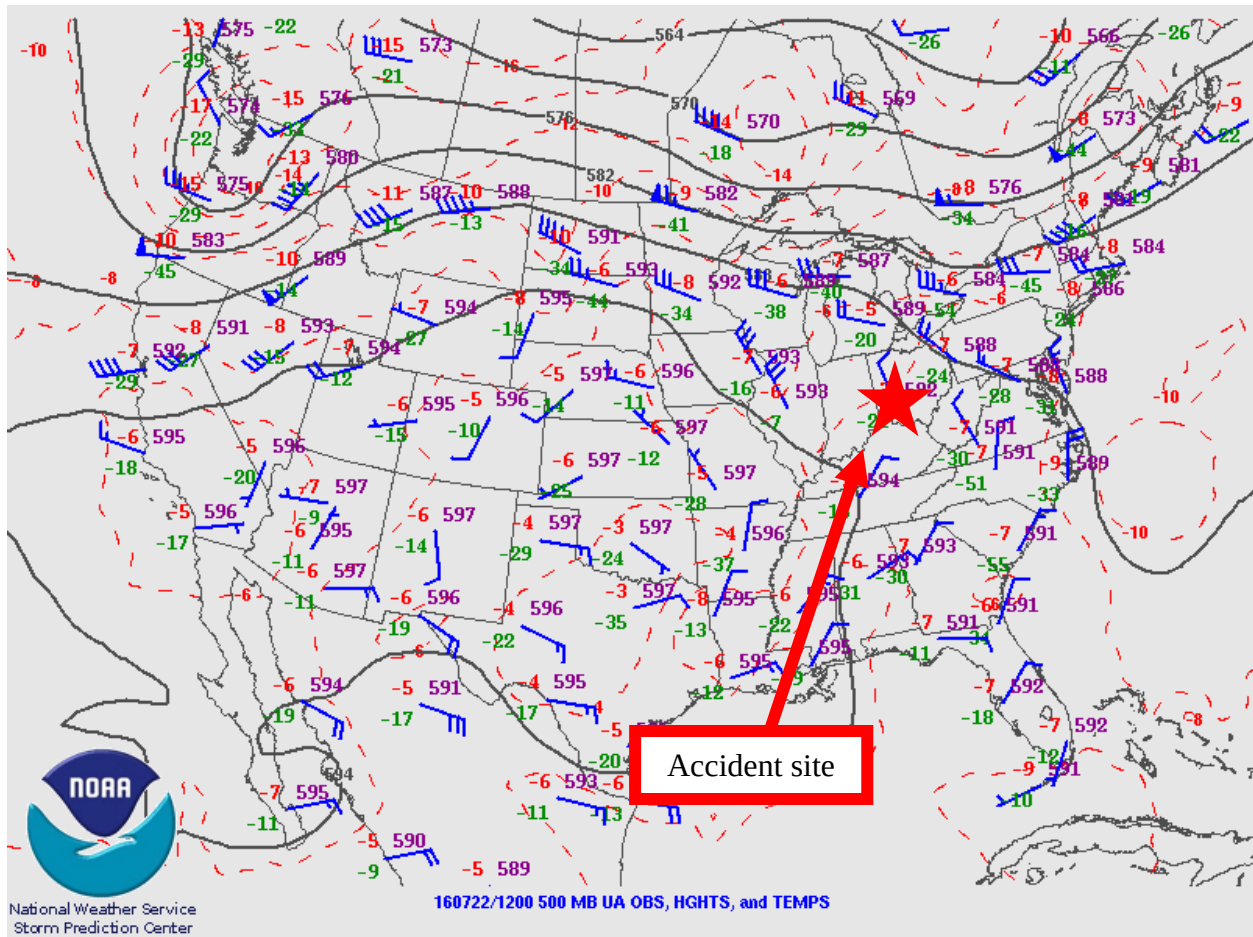


Figure 5 – 500-hPa Constant Pressure Chart for 0800 EDT

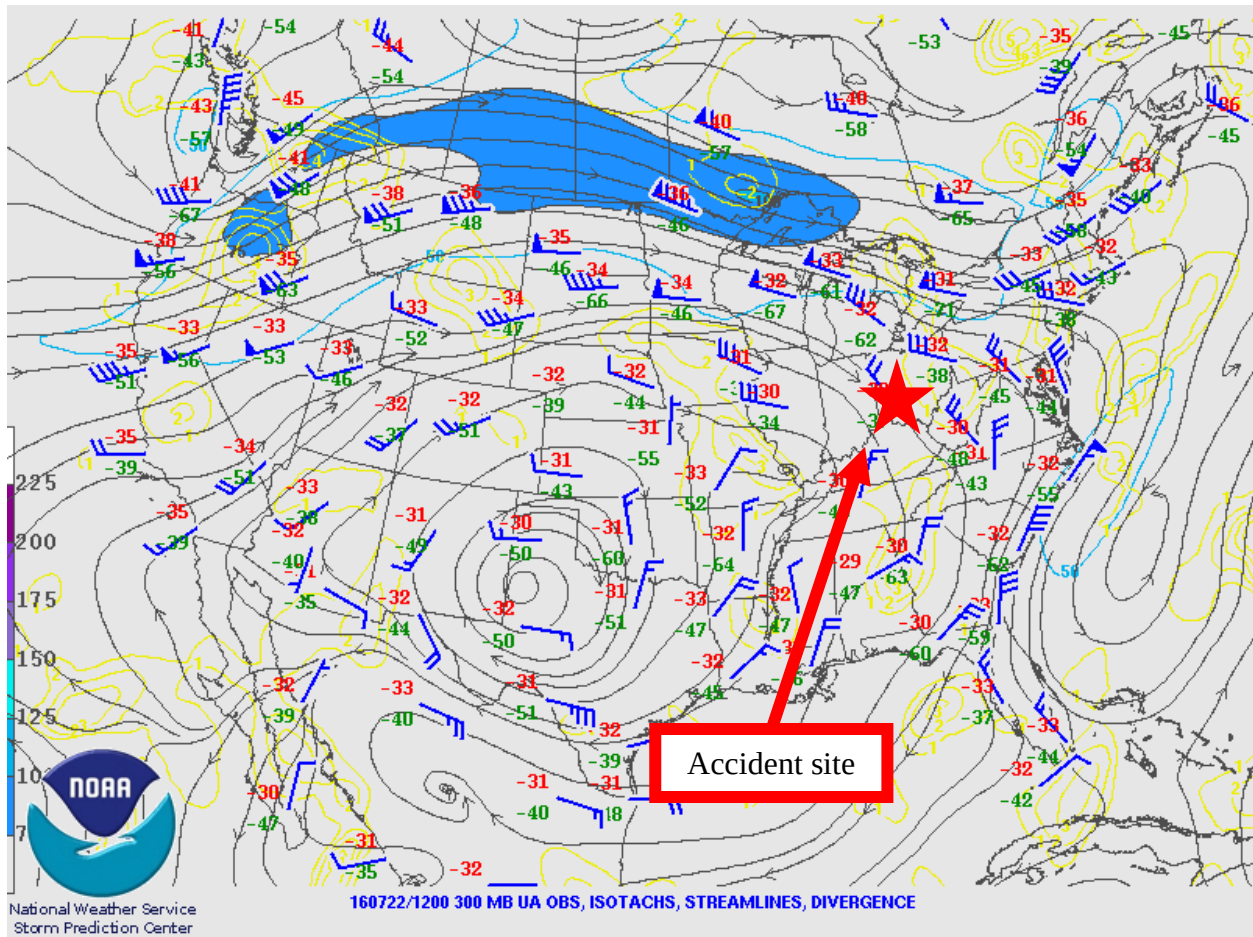


Figure 6 – 300-hPa Constant Pressure Chart for 0800 EDT

2.0 Storm Prediction Center Products

SPC issued the following Day 1 Convective Outlook at 0858 EDT (figure 7) with areas of thunderstorms and a marginal risk for severe thunderstorm forecast for the accident site. The accident site was located in an area where SPC forecasted a 5 percent chance of damaging thunderstorm winds or wind gusts 50 knots or greater within 25 miles of a point and a 5 percent chance of one inch diameter hail or larger within 25 miles of a point (figures 8 and 9). All of these severe weather chances were relatively high compared to climatology, given that on a normal summer day only a small chance of general thunderstorms would be forecast for the accident area with no chance of severe thunderstorms. The SPC Day 1 Convective Outlook valid at the time of the Lockheed Martin Flight Service (LMFS) weather briefing had identical thunderstorm, wind, and hail probabilities for the accident site at the accident time (section 16.0):³

SPC AC 221258

³ The bold sections in this NWS product and the rest of products in the weather study report are to highlight the individual sections that directly reference the weather conditions that affected the accident location around the accident time.

DAY 1 CONVECTIVE OUTLOOK
NWS STORM PREDICTION CENTER NORMAN OK
0758 AM CDT FRI JUL 22 2016

VALID 221300Z - 231200Z

...THERE IS AN ENH RISK OF SVR TSTMS PORTIONS DAKOTAS AND EXTREME
ERN MT...

...THERE IS A SLGT RISK OF SVR TSTMS SURROUNDING ENH RISK...

...THERE IS A SLGT RISK OF SVR TSTMS PORTIONS ERN MID ATLC AND NEW
ENGLAND...

...THERE IS A MRGL RISK OF SVR TSTMS ELSEWHERE FROM MID ATLC TO
LOWER OH VALLEY...PORTIONS DEEP S...CENTRAL HIGH PLAINS...AND NRN
PLAINS SURROUNDING THAT SLGT RISK...

...SUMMARY...

SEVERE STORMS WITH LARGE HAIL...DAMAGING WIND AND POSSIBLY A COUPLE
OF TORNADOES ARE EXPECTED OVER THE NORTHERN PLAINS THIS AFTERNOON
AND TONIGHT. FARTHER EAST...OCCASIONAL DAMAGING WIND GUSTS ARE
POSSIBLE THIS AFTERNOON AND EARLY EVENING OVER THE NORTHEAST UNITED
STATES.

...SYNOPSIS...

UPPER-AIR PATTERN THIS PERIOD WILL BE DOMINATED BY WWD-SHIFTING
ANTICYCLONE...CURRENTLY CENTERED OVER TX PANHANDLE. THIS FEATURE
WILL ERODE FROM E-W AS MULTIPLE/LOW-AMPLITUDE SHORTWAVES...SOME
CONVECTIVELY INDUCED/ENHANCED...PIVOT SWD AND SEWD OUT OF UPPER
GREAT LAKES REGION. DIFFUSE/FLATTER 500-MB ANTICYCLONE SHOULD BE
CENTERED OVER AZ BY END OF PERIOD...WITH RIDGE WWD ACROSS SRN CA AND
ENEWD ACROSS KS/OK BORDER REGION. MAIN BELT OF MIDLATITUDE WLVS
WILL REMAIN INVOF CANADIAN ORDER...PERTURBED PRIMARILY BY TWO
FEATURES...

1. SHORTWAVE TROUGH -- NOW EVIDENT IN MOISTURE-CHANNEL IMAGERY OVER
NWRN ONT -- FCST TO MOVE SEWD TO SERN QUE AND SERN ONT BY 00Z THEN
OVER NEW ENGLAND AROUND 12Z.
2. HIGH-AMPLITUDE SHORTWAVE TROUGH CURRENTLY MOVING INLAND PAC
NW...FCST TO CROSS NRN ROCKIES BETWEEN 00-06Z AND REACH SRN SK/ERN
MT BY END OF PERIOD.

AT SFC...11Z ANALYSIS SHOWED COLD FRONT FROM SWRN QUE SWWD ACROSS
CENTRAL LOWER MI...BECOMING WARM FRONT OVER SWRN WI/SRN MN AND ERN
SD...TO SFC LOW OVER CENTRAL SD. QUASISTATIONARY FRONTAL ZONE
EXTENDED FROM THERE WWD TO ANOTHER LOW BETWEEN WRL-BIL. LATTER LOW
SHOULD SHIFT/REDEVELOP NWD ACROSS CENTRAL MT BY 00Z...BY WHICH TIME
WARM FRONT SHOULD MOVE NWD TO SERN MT...DIAGONALLY ACROSS SD TO
CENTRAL IA AND CENTRAL IL. ERN LIMB OF FRONT WILL SHIFT EWD AS WEAK
COLD FRONT TO SRN QUE...CENTRAL PORTIONS NY/PA...AND NRN KY/SRN
INDIANA BY 00Z.

...NRN PLAINS...

ISOLATED TO SCATTERED TSTMS ARE EXPECTED TO DEVELOP THIS AFTN OVER
PORTIONS MT AND DAKOTAS. CONVECTION MAY DEVELOP INVOF SFC LOW AND

WARM FRONT SEWD FROM NRN MT ACROSS DAKOTAS. ENVIRONMENT WILL BE FAVORABLE FOR SUPERCELLS INVOF FRONTAL ZONE WITH POTENTIALLY VERY LARGE/DAMAGING HAIL...SVR DOWNDRAFT WINDS. CONDITIONAL POTENTIAL FOR TORNADOES EXISTS DEPENDING ON LONGEVITY OF RELATIVELY DISCRETE/MATURE SUPERCELL PHASES....ESPECIALLY OVER DAKOTAS WHERE GREATER MOISTURE WILL YIELD LOWER LCL. STORMS IN MT SHOULD BE HIGHER-BASED...BY CONTRAST.

LARGEST PRECONVECTIVE BUOYANCY AND STRONGEST SFC HEATING ARE EXPECTED FROM SWRN ND TO N-CENTRAL SD WHERE LOW-LEVEL MOISTURE WILL BE GREATEST...WITH SFC DEW POINTS COMMONLY UPPER 60S TO NEAR 70 F IN AND JUST N OF FRONTAL ZONE. THIS AIR MASS WILL BE SURMOUNTED BY STEEP MIDLEVEL LAPSE RATES ASSOCIATED WITH EML...YIELDING MLCAPE IN 2500-4000 J/KG RANGE. RELATIVELY BACKED SFC WINDS WILL CONTRIBUTE TO EFFECTIVE-SHEAR MAGNITUDES 45-55 KT. HODOGRAPHS SHOULD BE STRONGLY CURVED IN LOWEST COUPLE KM...THOUGH SIZE MAY BE LIMITED WITH SEWD EXTENT NEAR FRONT BY WEAK MAGNITUDES OF SFC-850-MB FLOW. LARGER HODOGRAPHS ARE EXPECTED OVER WRN ND AND ERN MT...WHERE MOISTURE WILL BE SOMEWHAT LOWER THAN FARTHER SE. LLJ IS EXPECTED TO STRENGTHEN CONSIDERABLY AFTER 00Z AS SHORTWAVE TROUGH APCHS AND LOW-LEVEL WAA INTENSIFIES. THIS WILL SUPPORT MAINTENANCE OF SOME CONVECTION AND LIKELY UPSCALE GROWTH THROUGH EVENING...RESULTING IN INCREASE IN DAMAGING-WIND RISK FOR A FEW HOURS.

...NERN CONUS...

WIDELY SCATTERED TO SCATTERED TSTMS ARE EXPECTED TO DEVELOP OVER THIS REGION...EPISODICALLY THROUGH AT LEAST EARLY EVENING. FOCI WILL INCLUDE SFC TROUGH AND WIND SHIFT FROM MAINE SWWD ACROSS MID ATLCL...AS WELL AS OUTFLOW AND DIFFERENTIAL-HEATING BOUNDARIES. MAIN CONCERNS WILL BE DAMAGING GUSTS...WITH ISOLATED LARGE HAIL ALSO POSSIBLE.

DEEP SHEAR IS FCST TO STRENGTHEN SOMEWHAT THROUGH AFTN AMIDST HEIGHT FALLS ALOFT...AS ONT PERTURBATION AND ASSOCIATED MID/UPPER-LEVEL SPEED MAX APCH. THIS WILL BE CONTERMINOUS WITH DIURNAL HEATING AND RELATED BOUNDARY-LAYER DESTABILIZATION...AMIDST SFC DEW POINTS COMMONLY 60S F. ONE WILD-CARD FACTOR IN TERMS OF INSTABILITY WILL BE EFFECT OF CLOUD COVER FROM ONGOING NON-SVR TSTMS ACROSS PORTIONS OH/PA/WRN NY. AS DISCUSSED IN PREVIOUS OTLK...FCST SOUNDINGS STILL SHOW CONSIDERABLE DRYING ALOFT ESPECIALLY OVER SRN PORTIONS OUTLOOK AREA...BEHIND LEADING PERTURBATION ASSOCIATED WITH MORNING CONVECTION IN MAINE. THIS...ALONG WITH WEAK LOW-LEVEL SHEAR/ CONVERGENCE DUE TO LIGHT AND WLY NATURE OF NEAR-SFC FLOW...MAY MUTE COVERAGE/INTENSITY OF CONVECTION SOMEWHAT. HOWEVER...FAVORABLE LOW-LEVEL MOISTURE/LAPSE RATES AND DEEP SPEED SHEAR SHOULD SUPPORT ORGANIZED MULTICELLS AND AT LEAST TRANSIENT SUPERCELL STRUCTURES IN SUSTAINED CONVECTION.

...ELSEWHERE...

WIDELY SCATTERED TO SCATTERED TSTMS...BOTH DISCRETE AND CLUSTERED...ARE EXPECTED TO FORM OVER BROAD SWATH FROM LOWER/MID MS VALLEY AND LOWER OH VALLEY ACROSS MID SOUTH AND AL TODAY. OUTFLOW BOUNDARIES FROM PRIOR OVERNIGHT STORMS...AS WELL AS DIFFERENTIAL-HEATING ZONES AND FRESHER OUTFLOWS FROM EARLY-AFTN CONVECTION...WILL SERVE AS MESOBETA-SCALE TO LOCAL FOCI FOR TSTM INITIATION AND MAINTENANCE. PRIMARY CONCERN WILL BE ISOLATED DAMAGING

DOWNDRAFTS...SOME WITH WINDS NEAR SVR LIMITS. WEAK SHEAR WILL LIMIT STORM ORGANIZATION EXCEPT WHERE SMALL-SCALE COLD POOLS CAN DRIVE LOCALIZED CONCENTRATION OF WIND-DAMAGE POTENTIAL.

..EDWARDS/DEAN.. 07/22/2016

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NOTE: THE NEXT DAY 1 OUTLOOK IS SCHEDULED BY 1630Z

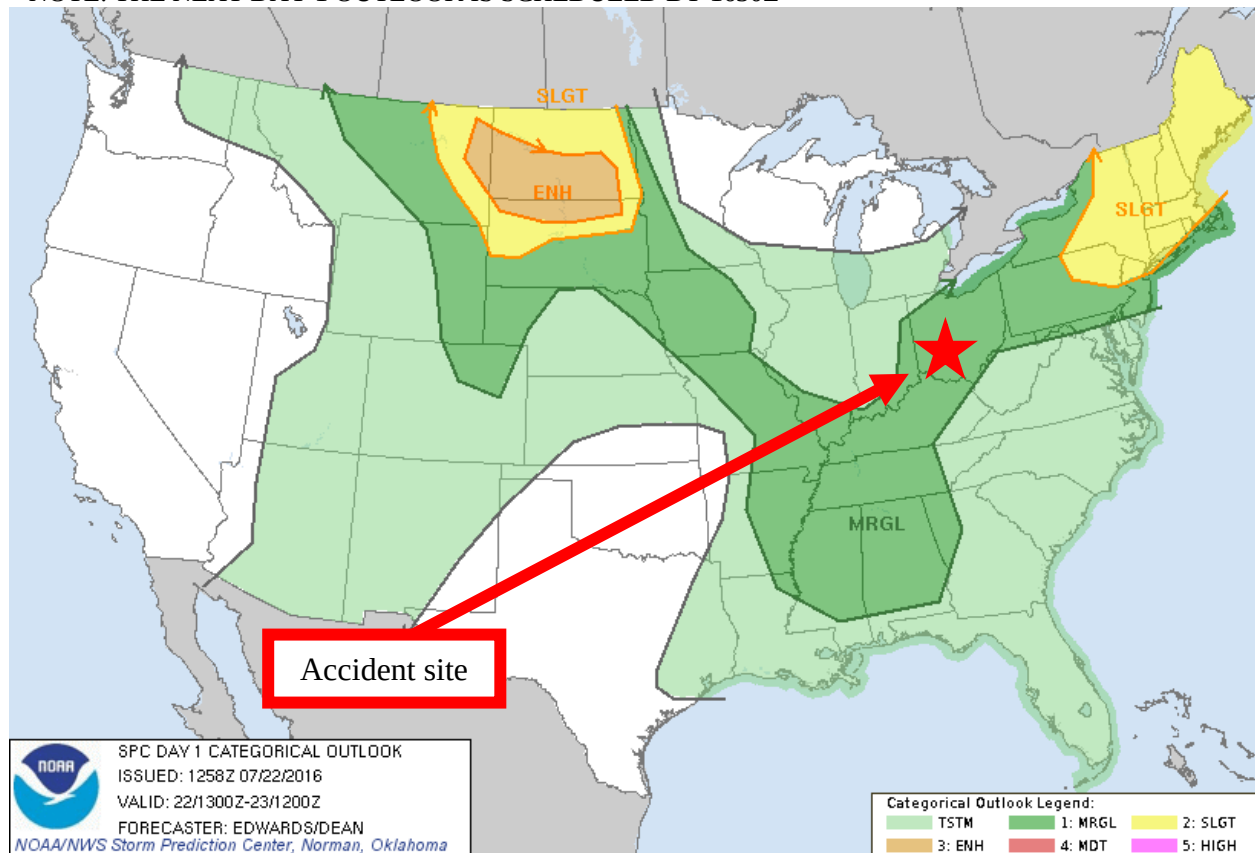


Figure 7 – SPC day 1 Convective Outlook valid at the time of the accident

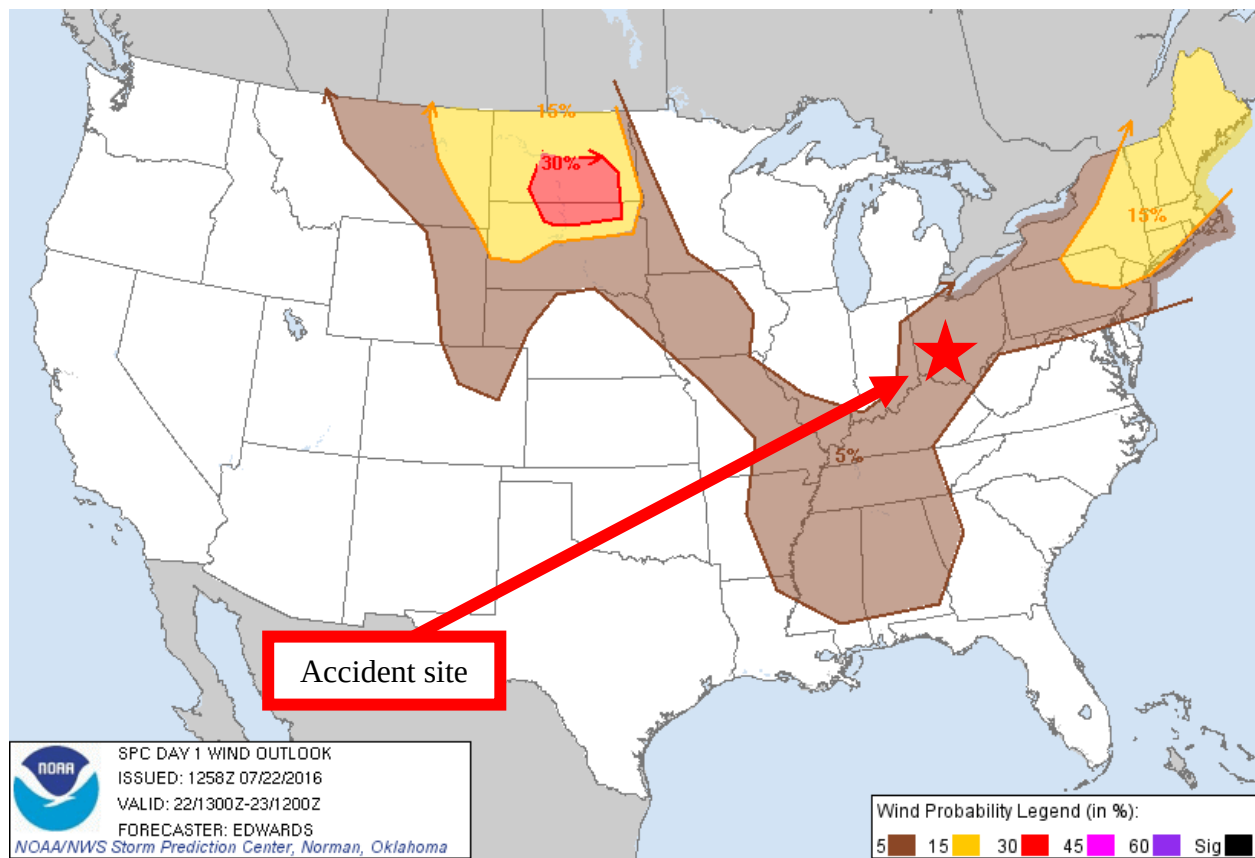


Figure 8 – SPC day 1 Wind Outlook valid at the time of the accident

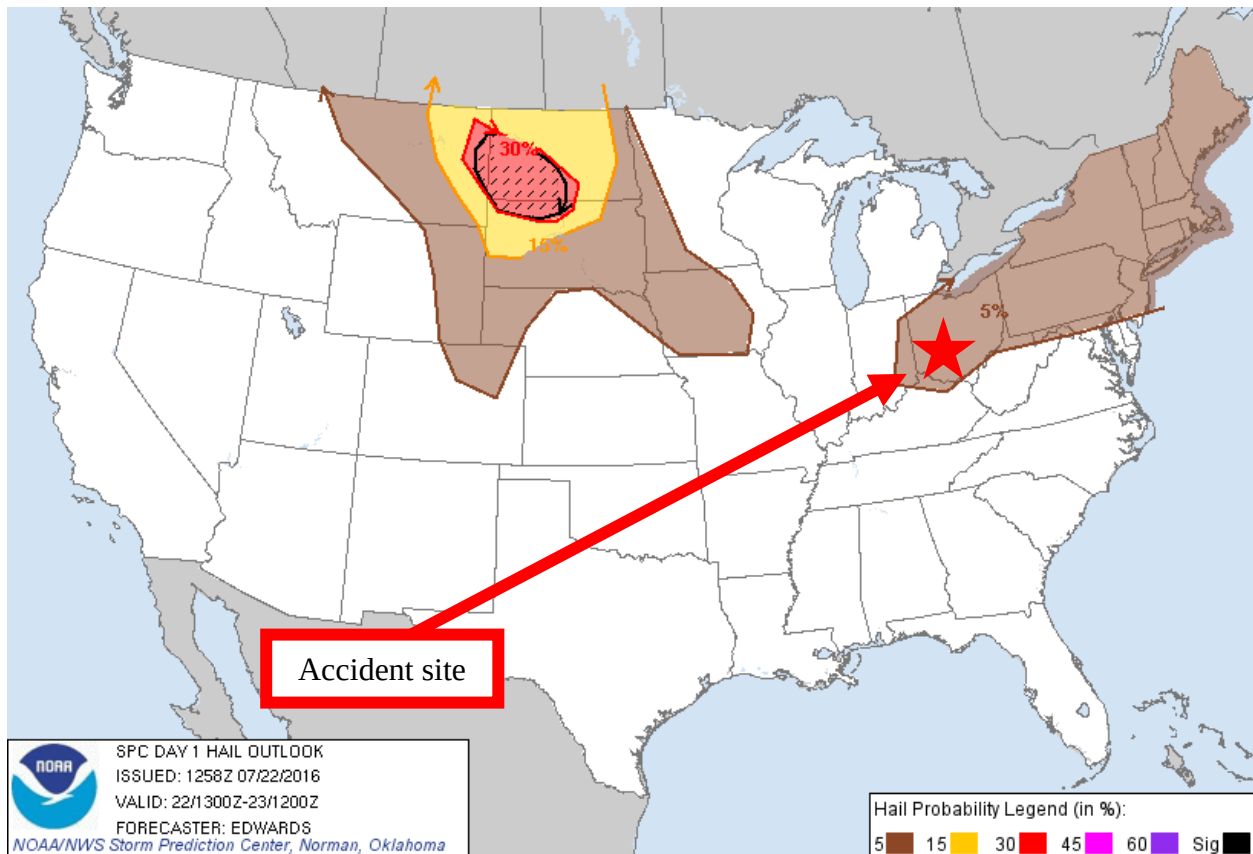


Figure 9 – SPC day 1 Hail Outlook valid at the time of the accident

3.0 Surface Observations

The area surrounding the accident site was documented utilizing official NWS Meteorological Aerodrome Reports (METARs) and Specials (SPECIs). The following observations were taken from standard code and are provided in plain language. Figure 10 is a local sectional map of the region with the accident site and the closest weather reporting locations marked.

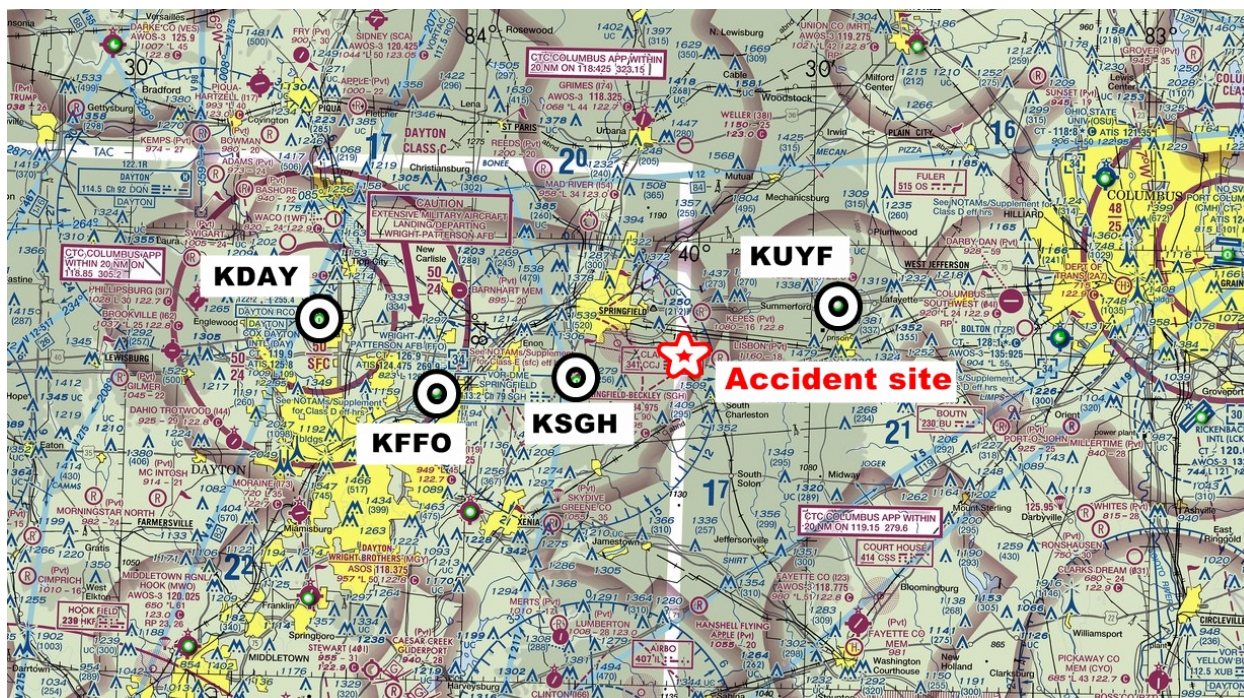


Figure 10 – Sectional Chart of southcentral Ohio with the location of the accident site and surface observation sites

Springfield-Beckley Municipal Airport (KSGH) had the closest official weather station to the accident site. KSGH had an Automated Weather Observing System (AWOS⁴) whose reports were not supplemented. KSGH was located 7 miles west-southwest of the accident site, at an elevation of 1,051 feet, and had a 4° westerly magnetic variation⁵ (figure 10). The following observations were taken and disseminated during the times surrounding the accident: ⁶

- [0456 EDT] KSGH 220856Z AUTO 10SM CLR 21/19 A3006 RMK AO2 SLP168 6//// T02110189 58012=
- [0556 EDT] KSGH 220956Z AUTO 18004KT 10SM CLR 22/19 A3005 RMK AO2 SLP164 T02170194=
- [0656 EDT] KSGH 221056Z AUTO 22005KT 10SM CLR 22/21 A3006 RMK AO2 SLP167 T02220206=

⁴ AWOS – Automated Weather Observing System is equipped with meteorological instruments to observe and report temperature, dewpoint, wind speed and direction, visibility, cloud coverage and ceiling up to twelve thousand feet, and altimeter setting.

⁵ Magnetic variation – The angle (at a particular location) between magnetic north and true north. 1985, latest measurement taken from <http://www.airnav.com/airport/KSGH>

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 affected 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.

[0756 EDT] KSGH 221156Z AUTO 22006KT 10SM CLR 24/22 A3006 RMK
AO2 SLP168 6//// 7//// T02390217 10239 20200 53001=

[0856 EDT] KSGH 221256Z AUTO 23006KT 10SM CLR 26/23 A3006 RMK
AO2 LTG DSNT N AND NE SLP169 T02610233=

[0941 EDT] KSGH 221341Z AUTO 26006KT 10SM BKN026 26/23 A3007 RMK
AO2 LTG DSNT NW-NE=

**[0956 EDT] KSGH 221356Z AUTO 24007KT 10SM BKN026 BKN039 OVC050
27/23 A3006 RMK AO2 LTG DSNT W-NE SLP170 T02670233=**

**[1007 EDT] KSGH 221407Z AUTO 26007KT 10SM VCTS BKN026 OVC039 26/23
RMK AO2 LTG DSNT ALQDS TSB01 \$=**

ACCIDENT TIME 1040 EDT

**[1056 EDT] KSGH 221456Z AUTO 04004KT 7SM TSRA BKN015 BKN020 OVC033
25/22 A3007 RMK AO2 LTG DSNT ALQDS TSB01RAB53 SLP175
P0000 6//// T02500222 53005=**

**[1109 EDT] KSGH 221509Z AUTO 00000KT 8SM -TSRA SCT017 BKN040 OVC050
24/23 A3008 RMK AO2 LTG DSNT ALQDS P0000=**

[1119 EDT] KSGH 221519Z AUTO 2 1/2SM +RA BR SCT011 BKN020 OVC046
23/21 A3008 RMK AO2 TSE18 P0027 TSNO=

[1126 EDT] KSGH 221526Z AUTO 00000KT 3SM TS BR SCT011 BKN028 OVC050
22/20 RMK AO2 LTG DSNT ALQDS TSE18B20RAE26 P0035 \$=

KSGH weather at 0956 EDT, wind from 240° at 7 knots, 10 miles visibility, a broken ceiling at 2,600 feet above ground level (agl), broken skies at 3,900 feet agl, overcast skies at 5,000 feet agl, temperature of 27° Celsius (C), dew point temperature of 23° C, and an altimeter setting of 30.06 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant⁷ west through northeast, sea level pressure 1017.0 hPa, temperature 26.7° C, dew point temperature 23.3° C.

KSGH weather at 1007 EDT, wind from 260° at 7 knots, 10 miles visibility, vicinity⁸ thunderstorms, a broken ceiling at 2,600 feet agl, overcast skies at 3,900 feet agl, temperature of 26° C, dew point temperature of 23° C, and missing an altimeter setting. Remarks: automated station with a precipitation discriminator, lightning distant all quadrants, thunderstorms began at 1001 EDT, maintenance is needed on the system.

⁷ Distant indicated that the lightning was beyond 10 miles but less than 30 miles from the center of the airport (or airport location point, ALP).

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

KSGH weather at 1056 EDT, wind from 040° at 4 knots, 7 miles visibility, thunderstorms and moderate rain, a broken ceiling at 1,500 feet agl, broken skies at 2,000 feet agl, overcast skies at 3,300 feet agl, temperature of 25° C, dew point temperature of 22° C, and an altimeter setting of 30.07 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant all quadrants, thunderstorms began at 1001 EDT, rain began at 1053 EDT, sea level pressure 1017.5 hPa, one-hourly precipitation of a trace, 6-hourly precipitation missing, temperature 25.0° C, dew point temperature 22.2° C, 3-hourly pressure increase of 0.5 hPa.

KSGH weather at 1109 EDT, wind calm, 8 miles visibility, thunderstorms and light rain, scattered clouds at 1,700 feet agl, a broken ceiling at 4,000 feet agl, overcast skies at 5,000 feet agl, temperature of 24° C, dew point temperature of 23° C, and an altimeter setting of 30.08 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant all quadrants, one-hourly precipitation of a trace.

Madison County Airport (KUYF) had an AWOS whose reports were not supplemented. KUYF was located 11 miles east-northeast of the accident site, at an elevation of 1,082 feet, and had a 6° westerly magnetic variation⁹ (figure 10). The following observations were taken and disseminated during the times surrounding the accident:

[0835 EDT] KUYF 221235Z AUTO 26007KT 10SM OVC110 26/23 A3005 RMK
AO2 LTG DSNT N AND NE=

[0855 EDT] KUYF 221255Z AUTO 27010G18KT 10SM SCT110 27/24 A3005
RMK AO2 LTG DSNT N AND NE=

[0915 EDT] KUYF 221315Z AUTO 27006G17KT 10SM BKN110 27/25 A3005
RMK AO2 LTG DSNT W THRU NE=

[0935 EDT] KUYF 221335Z AUTO 29008G19KT 10SM SCT120 27/25 A3006
RMK AO2 LTG DSNT NW THRU NE=

[0955 EDT] KUYF 221355Z AUTO 31004KT 10SM VCTS BKN030 BKN035 27/25
A3006 RMK AO2 LTG DSNT NW THRU NE=

**[1015 EDT] KUYF 221415Z AUTO 28021G29KT 1SM +TSRA BKN008 BKN018
OVC031 24/22 A3008 RMK AO2 LTG DSNT ALQS=**

**[1035 EDT] KUYF 221435Z AUTO 34007G17KT 1/2SM +TSRA SCT007 BKN010
OVC016 23/23 A3010 RMK AO2 LTG DSNT ALQS=**

ACCIDENT TIME 1040 EDT

⁹ Magnetic variation – The angle (at a particular location) between magnetic north and true north. 2000, latest measurement taken from <http://www.aimav.com/airport/KUYF>

**[1055 EDT] KUYF 221455Z AUTO 00000KT 2 1/2SM TSRA SCT013 BKN075
OVC090 23/23 A3009 RMK AO2 VIS 1 1/2V5 LTG DSNT ALQS=**

**[1115 EDT] KUYF 221515Z AUTO 21009KT 2 1/2SM VCTSRA SCT055 SCT065
OVC080 23/23 A3008 RMK AO2 LTG DSNT ALQS=**

**[1135 EDT] KUYF 221535Z AUTO 21009KT 7SM -TSRA SCT085 BKN110 22/22
A3006 RMK AO2 LTG DSNT ALQS=**

**[1155 EDT] KUYF 221555Z AUTO 21007KT 10SM -TSRA SCT100 BKN120
22/22 A3006 RMK AO2 LTG DSNT E THRU SW=**

KUYF weather at 1015 EDT, wind from 240° at 21 knots gusting to 29 knots, 1 mile visibility, thunderstorms and heavy rain, a broken ceiling at 800 feet agl, broken skies at 1,800 feet agl, overcast skies at 3,100 feet agl, temperature of 24° C, dew point temperature of 22° C, and an altimeter setting of 30.08 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant all quadrants.

KUYF weather at 1035 EDT, wind from 340° at 7 knots gusting to 17 knots, a half mile visibility, thunderstorms and heavy rain, scattered clouds at 700 feet agl, a broken ceiling at 1,000 feet agl, overcast skies at 1,600 feet agl, temperature of 23° C, dew point temperature of 23° C, and an altimeter setting of 30.10 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant all quadrants.

KUYF weather at 1055 EDT, wind calm, 2 and a half miles visibility, thunderstorms and moderate rain, scattered clouds at 1,300 feet agl, a broken ceiling at 7,500 feet agl, overcast skies at 9,000 feet agl, temperature of 23° C, dew point temperature of 23° C, and an altimeter setting of 30.09 inches of mercury. Remarks: automated station with a precipitation discriminator, visibility varying between 1 and a half miles and 5 miles, lightning distant all quadrants.

KUYF weather at 1115 EDT, wind from 210° at 9 knots, 2 and a half miles visibility, vicinity thunderstorms and moderate rain, scattered clouds at 5,500 feet agl, scattered clouds at 6,500 feet, an overcast ceiling at 8,000 feet agl, temperature of 23° C, dew point temperature of 23° C, and an altimeter setting of 30.08 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant all quadrants.

Wright-Patterson Air Force Base (KFFO) was the third closest official weather station to the accident site. KFFO had an official weather station whose reports were supplemented by a weather observer. KFFO was located 17 miles west-southwest of the accident site, at an elevation of 823 feet, and had a 4° westerly magnetic variation¹⁰ (figure 10). The following observations were taken and disseminated during the times surrounding the accident:

**[0928 EDT] KFFO 221328Z 21006KT 10SM TS SCT026 BKN055 BKN120 27/24
A3004 RMK AO2A SLP169=**

¹⁰ Magnetic variation – The angle (at a particular location) between magnetic north and true north. 1990, latest measurement taken from <http://www.airnav.com/airport/KFFO>

[0941 EDT] KFFO 221341Z 23008KT 10SM TS SCT027 BKN055 BKN120 27/24
A3005 RMK AO2A LTG DSNT N-NE SLP171=

[0958 EDT] KFFO 221358Z 25008KT 10SM VCTS SCT033 BKN055 BKN120
27/24 A3005 RMK AO2A LTG DSNT NE SLP172 T02720243=

[1012 EDT] KFFO 221412Z 27007KT 10SM VCTS FEW026 BKN035 OVC050
28/25 A3004 RMK AO2A LTG DSNT N-NE AND S SLP170=

**[1028 EDT] KFFO 221428Z 28007KT 10SM VCTS SCT015 OVC026 27/24
A3004 RMK AO2A LTG DSNT NE CIG 015V036 SLP170=**

**[1038 EDT] KFFO 221438Z 36006KT 10SM VCTS SCT015 OVC026 27/24
A3004 RMK AO2A LTG DSNT NE AND W SCT015 V BKN SLP169=**

ACCIDENT TIME 1040 EDT

**[1042 EDT] KFFO 221442Z VRB02KT 10SM TS SCT015 OVC026 26/24 A3004
RMK AO2A LTG DSNT NE AND W SCT015 V BKN SLP171=**

**[1048 EDT] KFFO 221448Z 32005KT 1SM R23R/2000VP6000FT TSRA BR
BKN015 OVC021 26/24 A3005 RMK LTG DSNT NE AND
SW-W SLP172=**

[1052 EDT] KFFO 221452Z 31007KT 3SM R23R/P6000FT TSRA BR BKN015
OVC025 26/25 A3005 RMK AO2A VIS N-NE 1 LTG DSNT
E AND SW-W SLP173=

[1058 EDT] KFFO 221458Z 28009KT 250V340 3SM -TSRA BR SCT015 BKN025
OVC050 26/25 A3005 RMK AO2A LTG DSNT NE-E AND
SW-W SLP173 P0018 60018 T02590250 52006=

[1105 EDT] KFFO 221505Z 27011KT 1SM R23R2200VP6000FT TSRA BR SCT015
BKN025 OVC050 25/24 A3006 RMK AO2A LTG DSNT NE
AND SE AND SW-W SLP175=

[1118 EDT] KFFO 221518Z 25015G24KT 1SM R23R/5500FT +TSRA BR SCT015
OVC023 24/22 A3006 RMK AO2A LTG DSNT NE-E AND S-W SLP175=

KFFO weather at 1028 EDT, wind from 280° at 7 knots, 10 miles visibility, vicinity thunderstorms, scattered clouds at 1,500 feet agl, an overcast ceiling at 2,600 feet agl, temperature of 27° C, dew point temperature of 24° C, and an altimeter setting of 30.04 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant northeast, ceiling varying between 1,500 and 3,600 feet agl, sea level pressure 1017.0 hPa.

KFFO weather at 1038 EDT, wind from 360° at 6 knots, 10 miles visibility, vicinity thunderstorms, scattered clouds at 1,500 feet agl, an overcast ceiling at 2,600 feet agl, temperature of 27° C, dew point temperature of 24° C, and an altimeter setting of 30.04 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant northeast and west, scattered clouds at 1,500 feet agl were variable to broken ceiling, sea level pressure 1016.9 hPa.

KFFO weather at 1042 EDT, variable wind at 2 knots, 10 miles visibility, thunderstorms, scattered clouds at 1,500 feet agl, an overcast ceiling at 2,600 feet agl, temperature of 26° C, dew point temperature of 24° C, and an altimeter setting of 30.04 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant northeast and west, scattered clouds at 1,500 feet agl were variable to broken ceiling, sea level pressure 1017.1 hPa.

KFFO weather at 1048 EDT, wind from 320° at 5 knots, 1 mile visibility, runway visual range on runway 23R varying between 2,000 feet and greater than 6,000 feet visibility, thunderstorms and moderate rain, mist, broken ceiling at 1,500 feet agl, overcast skies at 2,100 feet agl, temperature of 26° C, dew point temperature of 24° C, and an altimeter setting of 30.05 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning distant northeast and southwest through west, sea level pressure 1017.2 hPa.

The observations from KSGH, KFFO, and KUYF surrounding the accident time indicated MVFR¹¹ to IFR¹² conditions due to visibilities in thunderstorms and moderate to heavy rain, with lightning in all quadrants, and gusty surface winds. Given the thunderstorm activity around and at the accident site at the accident time (sections 6.4 and 6.5) severe turbulence, lightning, large hail, extensive surface wind gusts, and turbulence would have all been likely and the surface observations matched the expected conditions.

¹¹ 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 feet agl and/or 3 to 5 miles visibility.

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

4.0 Upper Air Data

The closest official upper air sounding to the accident site was from Wilmington, Ohio, (KILN), located 27 miles south of the accident site, with a site number 72426, and an elevation of 1,007 feet. The 0800 EDT sounding was plotted on a standard Skew-T log P diagram¹³ with the derived stability parameters included in figure 11 (with data from the surface to 200-hPa, or 40,000 feet msl.) This data was analyzed utilizing the RAOB¹⁴ software package. The sounding depicted the Lifted Condensation Level (LCL)¹⁵ at 1,905 feet, a Convective Condensation Level (CCL)¹⁶ of 6,836 feet, and a Level of Free Convection (LFC)¹⁷ at 14,138 feet. The freezing level was located at 15,280 feet. The precipitable water value was 1.63 inches.

¹³ Skew T log P diagram – is a standard meteorological plot using temperature and the logarithmic of pressure as coordinates, used to display winds, temperature, dew point, and various indices used to define the vertical structure of the atmosphere.

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

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

¹⁶ Convective Condensation Level (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.

¹⁷ Level of Free Convection (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.

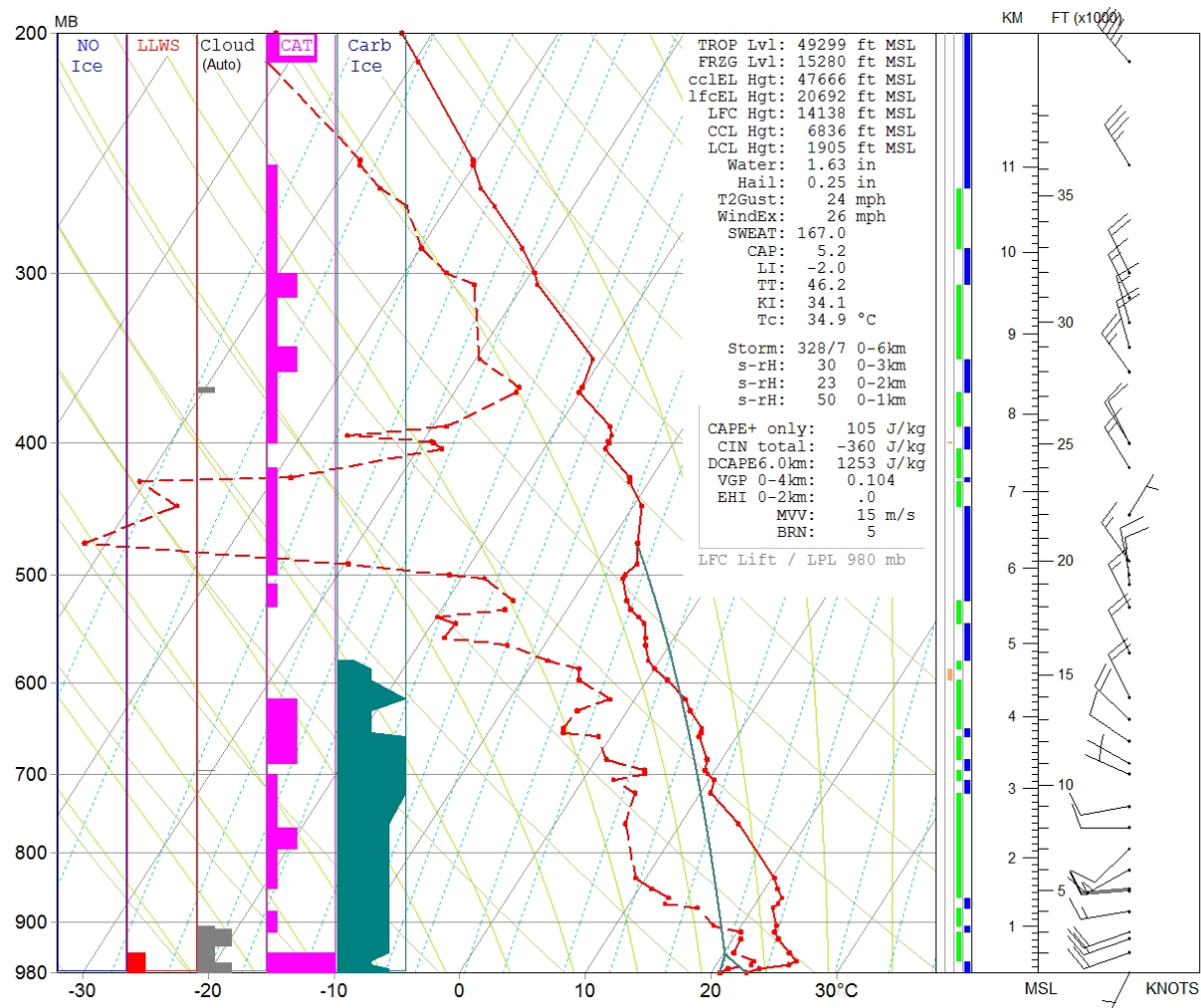


Figure 11 – 0800 EDT KILN sounding

The 0800 EDT KILN sounding indicated a conditionally unstable environment with 105 J/kg of CAPE¹⁸. This environment would have been supportive of cloud formation, rain showers, and thunderstorms, if a lifting mechanism was in the area of the accident site at the accident time (sections 1.1 and 1.2). The maximum vertical velocity (MVV) possible within rain showers or thunderstorm updrafts in the 0800 EDT KILN sounding was 15 meters per second (m/s) or 29 knots. By the 2000 EDT KILN sounding (not shown) the MVV had risen to 51 m/s or 99 knots. Given the amount of thunderstorm activity in the area of the accident site at the accident time (sections 6.4, 6.5, and 6.6), the maximum vertical velocities within the thunderstorm updrafts were likely closer to 99 knots. RAOB identified the possibility of clouds between the surface and 4,000 feet. No areas of icing were indicated by RAOB outside of rain showers or thunderstorms. With rain showers and thunderstorms possible given the environment, the 0800 EDT KILN sounding indicated the strongest wind speeds possible with a microburst, outflow boundary, or gust front would have been 24 mph (21 knots) as indicated by the T2Gust parameter or 26 mph (23 knots) as indicated by the WindEx parameter.

¹⁸ Convective Available Potential Energy (CAPE) – CAPE is a measure of the amount of energy available for convection and is directly related to the maximum potential vertical speed within an updraft.

The 0800 EDT KILN sounding wind profile indicated a surface wind from 205° at 6 knots with the wind remaining primarily west to northwesterly through 40,000 feet. The wind speed increased from 6 knots at the surface to 20 knots by 2,000 feet. The wind speed then remained between 10 and 20 knots all the way to 34,000 feet. The possibility of low-level wind shear (LLWS) was indicated by RAOB for the environment outside of thunderstorms between the surface and 2,000 feet, and several layers of possible clear-air turbulence were indicated between the surface and 40,000 feet.

5.0 Satellite Data

Visible and infrared data from the Geostationary Operational Environmental Satellite number 13 (GOES-13) data was obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the NTSB's Man-computer Interactive Data Access System software. Visible and infrared imagery (GOES-13 band 1 and 4) at wavelengths of 0.65 microns (μm) and 10.7 μm , respectively, were retrieved for the period. Satellite imagery surrounding the time of the accident, from 0830 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 12 and 13 present the GOES-13 visible imagery from 1045 and 1115 EDT at 2X magnification. Inspection of the visible imagery indicated cumuliform type clouds above the accident site at the accident time. Overshooting tops are also apparent to the east of the accident site and KSGH. The cumuliform cloud cover grew and moved southeastward from central Ohio and Indiana over the accident site between 0745 and 1200 EDT (attachment 1). Figures 14 and 15 present the GOES-13 infrared imagery from 1045 and 1115 EDT at 6X magnification with the accident site highlighted with a red square. The infrared imagery indicated cooler brightness temperatures and cloud tops (green and blue colors) located above the accident site and between KFFO and the accident site around the accident time. The convective activity was likely increasing in coverage and intensity between 1045 and 1115 EDT (figures 14 and 15) as the amount of colder brightness temperatures between KFFO and the accident site increased between 1045 and 1115 EDT. Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 0800 EDT KILN sounding, the approximate cloud-top heights over the accident site were 37,000 feet at 1045 EDT. It should be noted these figures have not been corrected for any parallax error.

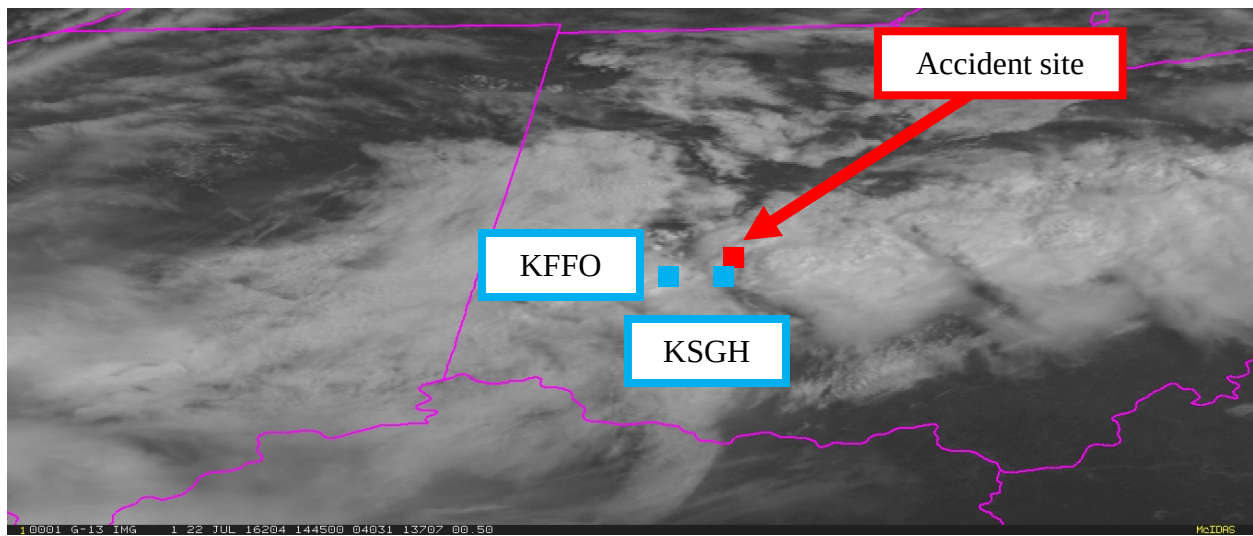


Figure 12 – GOES-13 visible image at 1045 EDT

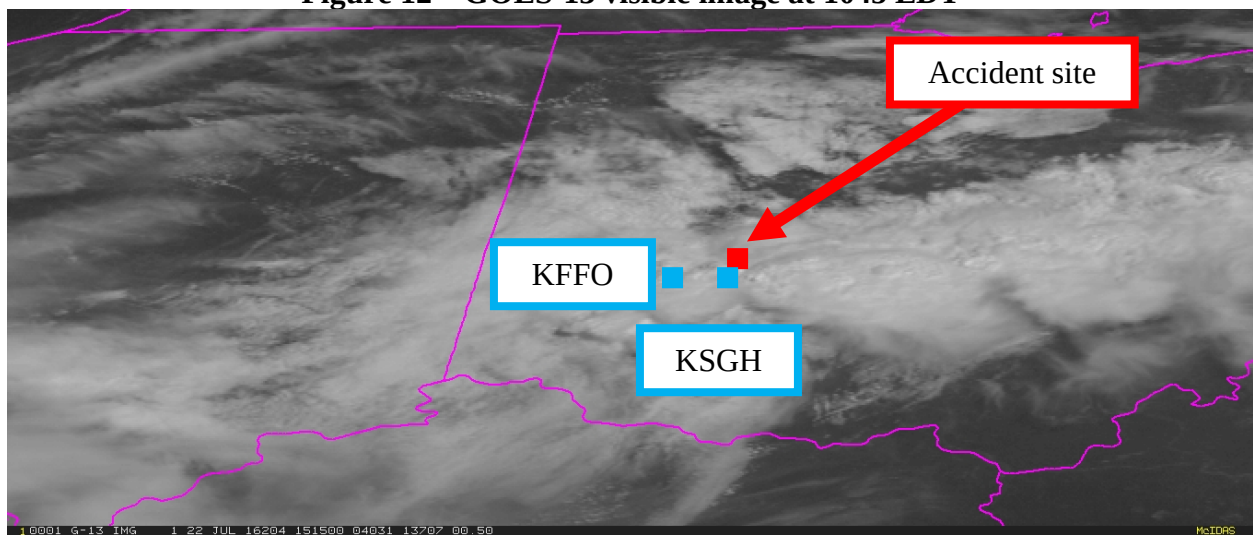


Figure 13 – GOES-13 visible image at 1115 EDT

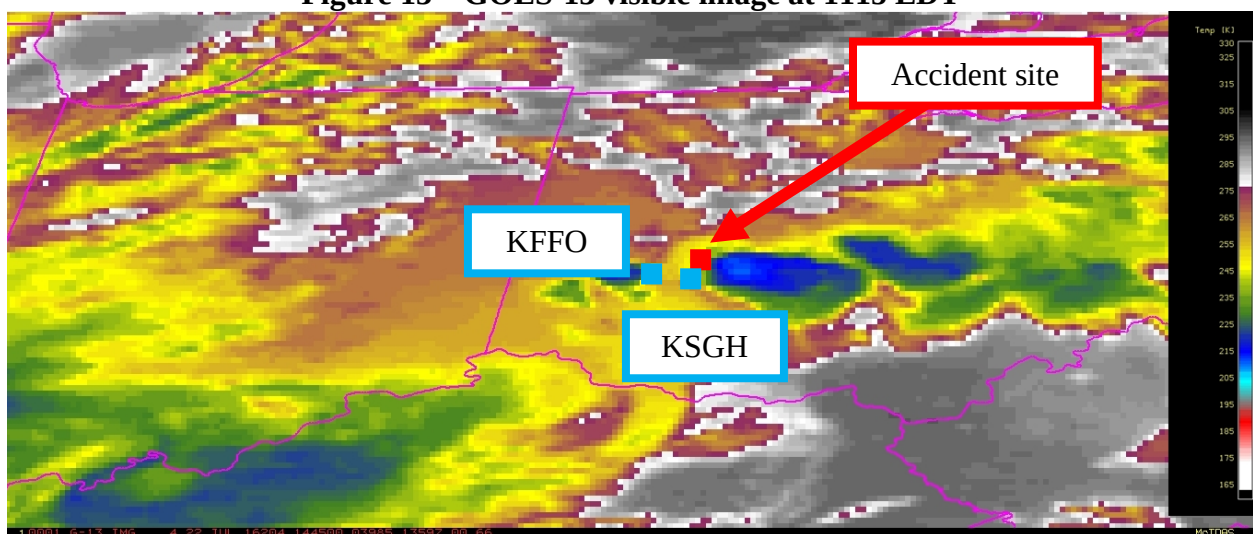


Figure 14 – GOES-13 infrared image at 1045 EDT

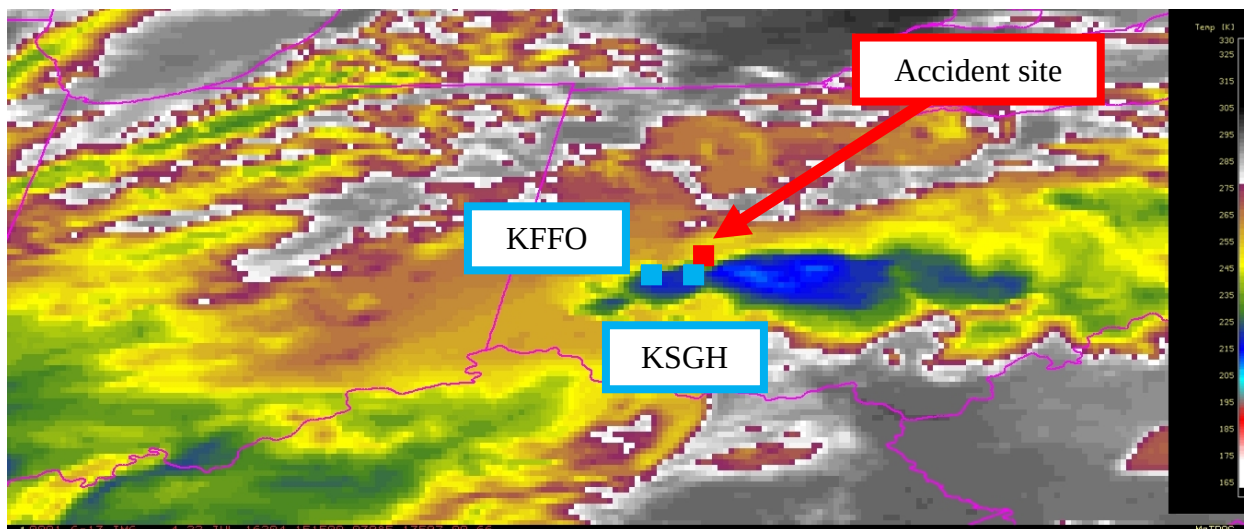


Figure 15 – GOES-13 infrared image at 1115 EDT

6.0 Radar Imagery Information

The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)¹⁹ to the accident site was the Wilmington, Ohio, radar (KILN), which was located 23 miles south of the accident site at an elevation of 1,056 feet. Level II and III archive radar data were obtained from the NCEI utilizing the NEXRAD Data Inventory Search and displayed using the NOAA’s Weather and Climate Toolkit software.

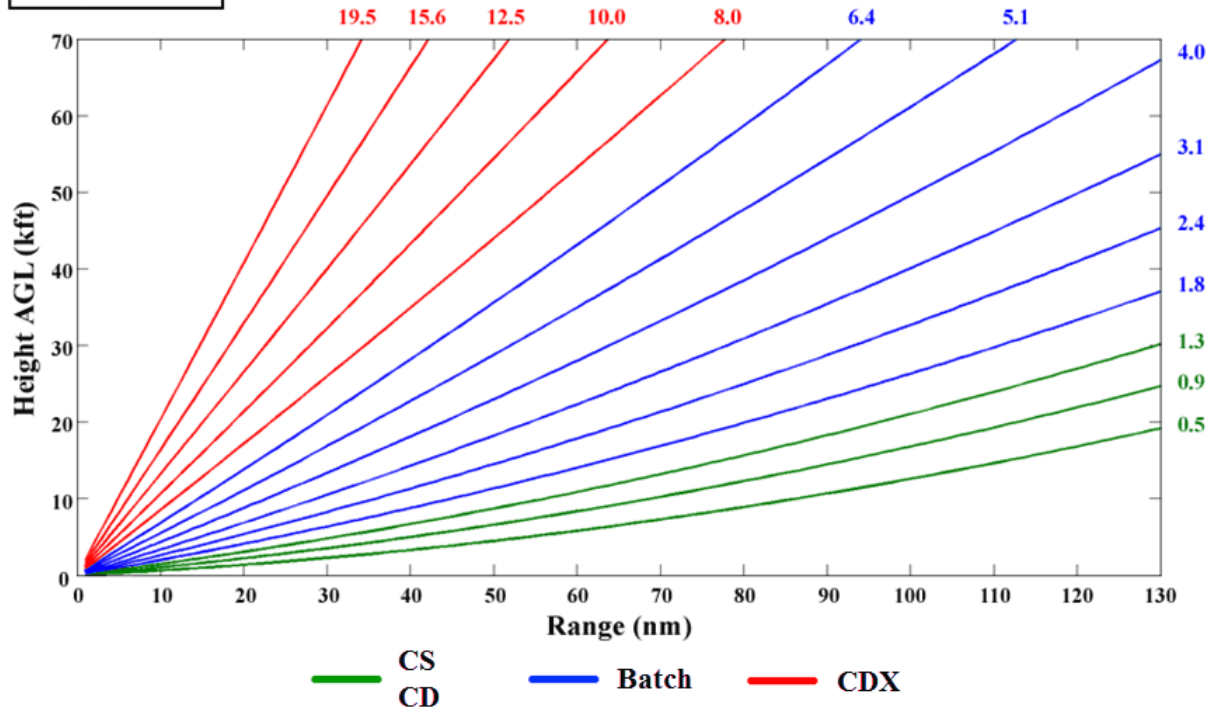
6.1 Volume Scan Strategy

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 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 three common scanning strategies. The most common is where the radar makes 14 elevation scans from 0.5° to 19.5° every four and a half minutes. This particular scanning strategy is documented as volume coverage pattern 12 (VCP-12). 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 KILN WSR-88D radar was operating in the precipitation mode (Mode A, VCP-12). 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.

¹⁹ The WSR-88D is an S-band 10-centimeter wavelength radar with a power output of 750,000 watts, and with a 28-foot parabolic antenna that concentrates the energy between a 0.87° and 0.96° beam width. The radar produces three basic types of products: base reflectivity, base radial velocity, and base spectral width.

VCP 12



VCP-12 Precipitation Mode Scan Strategy²⁰

6.2 Beam Height Calculation

Assuming standard refraction²¹ of the WSR-88D 0.95° wide radar beam, the following table shows the approximate beam height and width²² information²³ of the radar display over the site of the accident. The heights have been rounded to the nearest 10 feet.

²⁰ Contiguous Surveillance (CS)--The low PRF scan of the split cut. Gives a high $R_{\max}$ value to determine proper target location and intensity, but a low $V_{\max}$ value limits the velocities that can be measured.

Contiguous Doppler (CD)--The high PRF scan of the split cut. Gives a low $R_{\max}$ value causing more range folded (multiple trip) echoes, but a high $V_{\max}$ value to get higher, more accurate velocity values.

Batch Mode – Uses alternating low and high PRFs on each radial for one full rotation at each elevation angle. The two resulting data sets (low PRF and high PRF) are combined to resolve range ambiguity. Used in the middle elevation angles.

W – With range unfolding (W)

WO – Without range unfolding (WO)

²¹ Standard Refraction in the atmosphere is when the temperature and humidity distributions are approximately average, and values set at the standard atmosphere.

²² Beam width – A measure of the angular width of a radar beam.

²³ Beamwidth values are shown for legacy resolution products. Super resolution products would have an effective beamwidth that would be approximately half these values.

ANTENNA ELEVATION	BEAM CENTER	BEAM BASE	BEAM TOP	BEAM WIDTH
0.5°	2,660 feet	1,530 feet	3,790 feet	2,260 feet
1.8°	5,820 feet	4,690 feet	6,950 feet	2,260 feet
2.4°	7,280 feet	6,150 feet	8,400 feet	2,260 feet

Based on the radar height calculations, the 0.5°, 1.8°, and 2.4° elevation scans depicted the conditions between 1,530 feet and 8,400 feet msl over the accident site and these are the closest altitudes to the accident flight level before the accident occurred.²⁴

6.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors²⁵ it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in decibels (dBZ²⁶), and is a general measure of echo intensity. FAA Advisory Circular AC 00-24C, “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:

²⁴ For more information, please see the air traffic control (ATC) data located in the docket for this accident.

²⁵ Hydrometeors are any product of condensation or sublimation of atmospheric water vapor, whether formed in the free atmosphere or at the earth’s surface; also, any water particles blown by the wind from the earth’s surface. Hydrometeors are classified as; (a) Liquid or solid water particles suspended in the air: cloud, water droplets, mist or fog. (b) Liquid precipitation: drizzle and rain. (c) Freezing precipitation: freezing drizzle and freezing rain. (d) Solid (frozen) precipitation: ice pellets, hail, snow, snow pellets, and ice crystals. (e) Falling particles that evaporate before reaching the ground: virga. (f) Liquid or solid water particles lifted by the wind from the earth’s surface: drifting snow, blowing snow, blowing spray. (g) Liquid or solid deposits on exposed objects: dew, frost, rime, and glazed ice.

²⁶ dBZ – A non-dimensional “unit” of radar reflectivity which represents a logarithmic power ratio (in decibels , or dB) with respect to radar reflectivity factor, Z.

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

6.4 Regional Weather Radar Summary

Figures 16 and 17 provide a radar summary image from 1045 and 1115 EDT with reflectivity values over the northeastern United States. The accident site was located in an area of 40 to 55 dBZ values at 1045 and 1115 EDT. These reflectivity values indicated heavy to extreme echoes at the accident site around the accident time with severe turbulence, lightning, large hail, extensive surface wind gusts, and turbulence all likely. Another area of heavy to extreme echoes was located over western Pennsylvania.

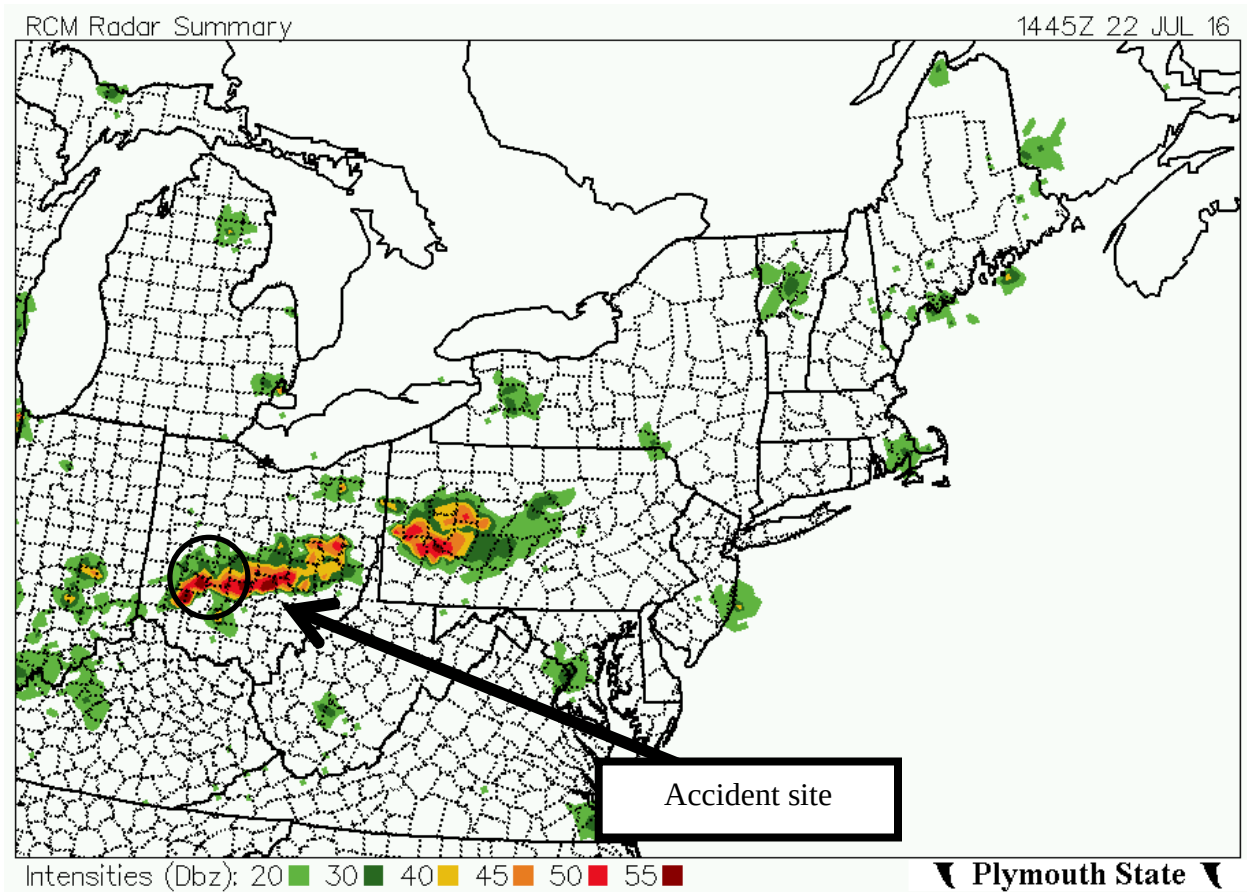


Figure 16 – Radar summary image for 1045 EDT with the accident site

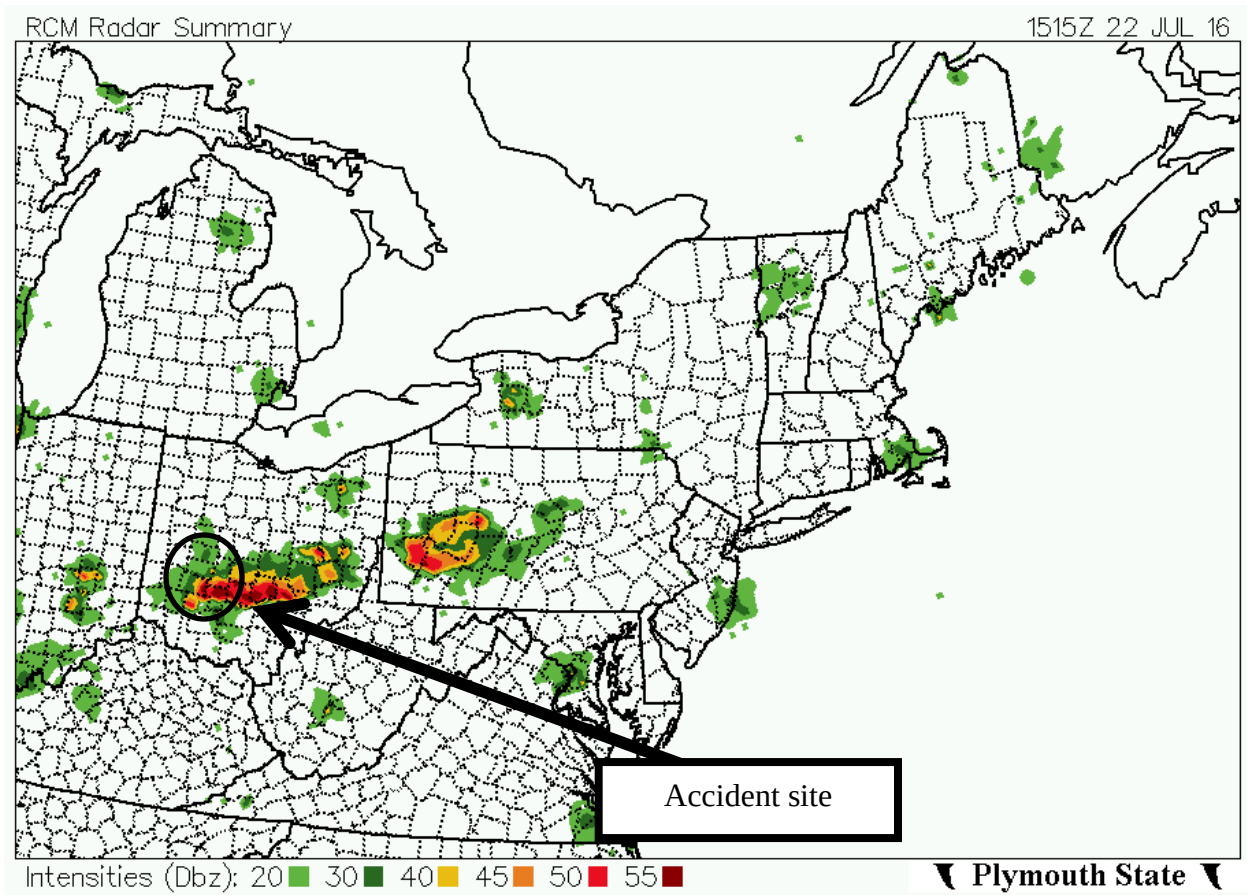


Figure 17 – Radar summary image for 1115 EDT with the accident site

6.5 Base Reflectivity and Lightning Data

Figures 18 through 28 present the KILN WSR-88D base reflectivity images for the 0.5° elevation scans initiated at 1036, 1038, 1041, 1043, and 1103 EDT with a resolution of 0.5° X 250 m, the base reflectivity images for the 1.8° elevation scans initiated at 1035, 1040, and 1045 EDT, and the base reflectivity images for the 2.4° elevation scans initiated at 1035, 1040, and 1045 EDT with a resolution of 1.0° X 1 km, respectively. The air traffic control (ATC) flight track is also included with the arrows pointing in the direction of travel. The accident flight track indicated that the accident flight flew through an area of 10 to 40 dBZ reflectivity values located along the route of flight before the accident time. 25 to 40 dBZ reflectivity values were located above the accident site at the accident time. The reflectivity values above the accident site at the accident time would correspond to light to heavy rain (section 6.3). In addition, the accident flight flew into the thunderstorms at the same time that an outflow boundary (section 17, figure 28, attachment 2) was moving southward above the accident site. As the outflow boundary moved southward across the accident site there was a corresponding increase in the dBZ values in the base reflectivity data around the accident site. There were lightning flashes²⁷ and strikes surrounding the accident site around the accident time with over 900 lightning flashes associated with the thunderstorms between 1030 and 1040 EDT. The accident flight was located within 2 miles of the lightning flashes after 1037:02 EDT through the accident time. Due to the accident flight's penetration of the outflow boundary and the thunderstorms, the accident flight likely encountered heavy precipitation, severe to extreme turbulence, updrafts and downdrafts, and wind shear around the accident time (section 17). Attachments 2, 3, and 4 provide additional base reflectivity data.

²⁷ Lightning Flash – This is one contiguous conducting channel and all the current strokes/pulses that flow through it. There are two types of flashes: ground flashes and cloud flashes.

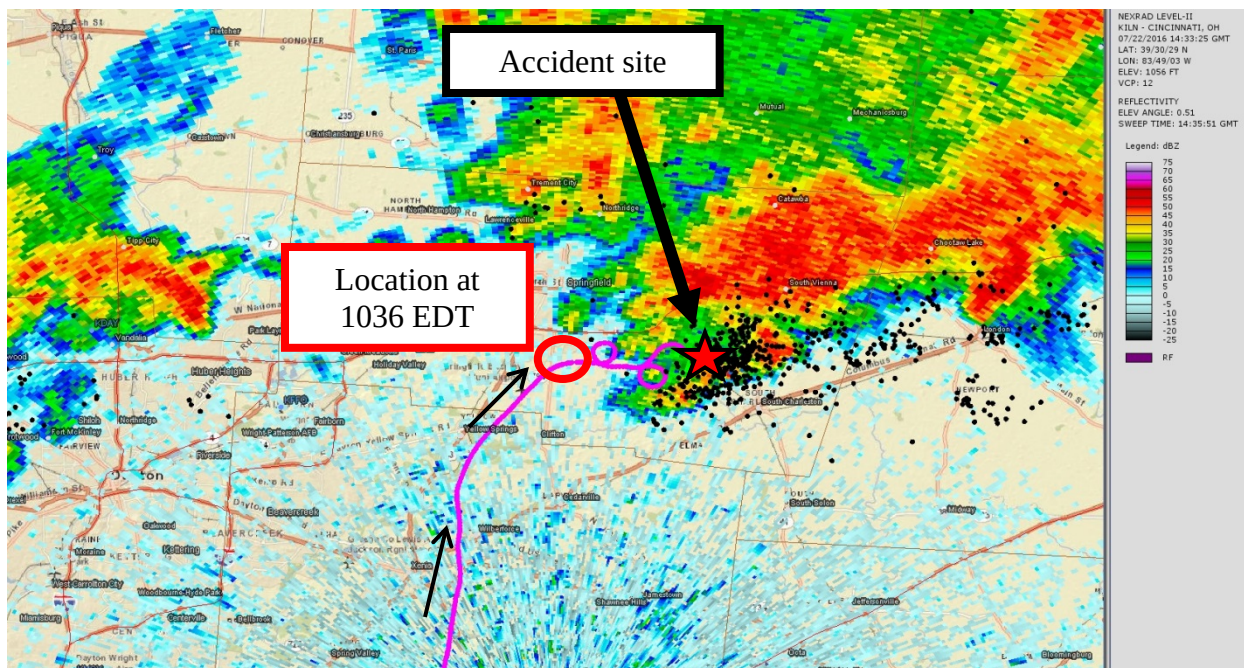


Figure 18 – KILN WSR-88D reflectivity for the 0.5° elevation scan initiated at 1036 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

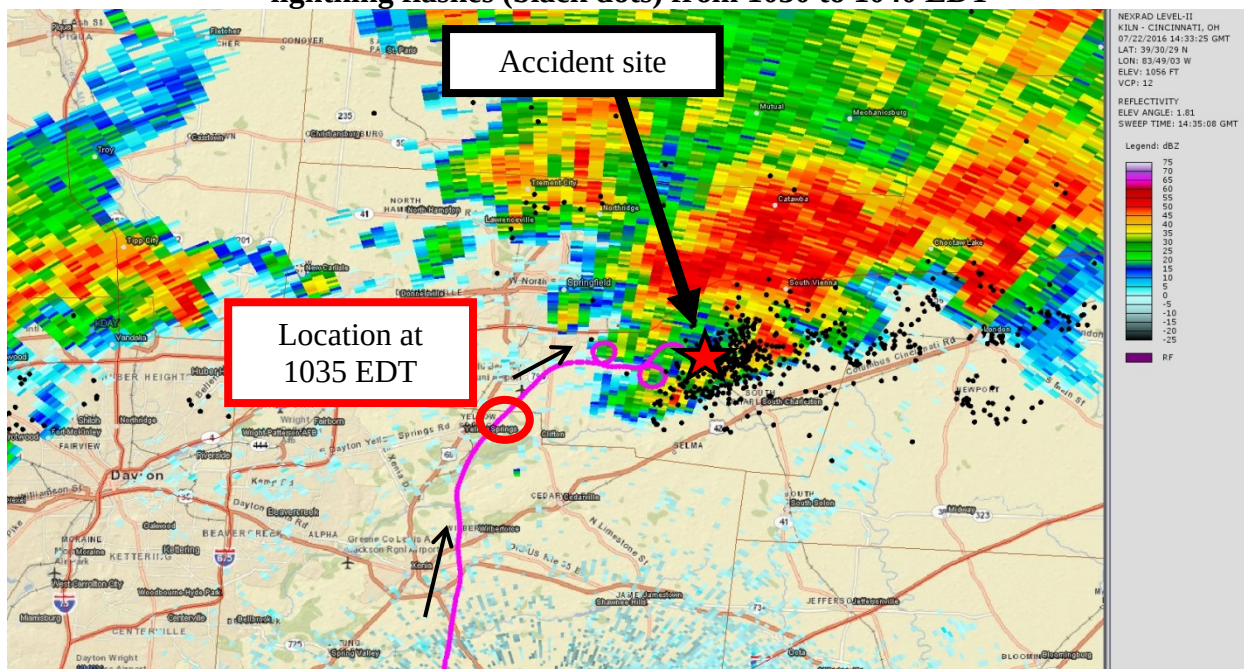


Figure 19 – KILN WSR-88D reflectivity for the 1.8° elevation scan initiated at 1035 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

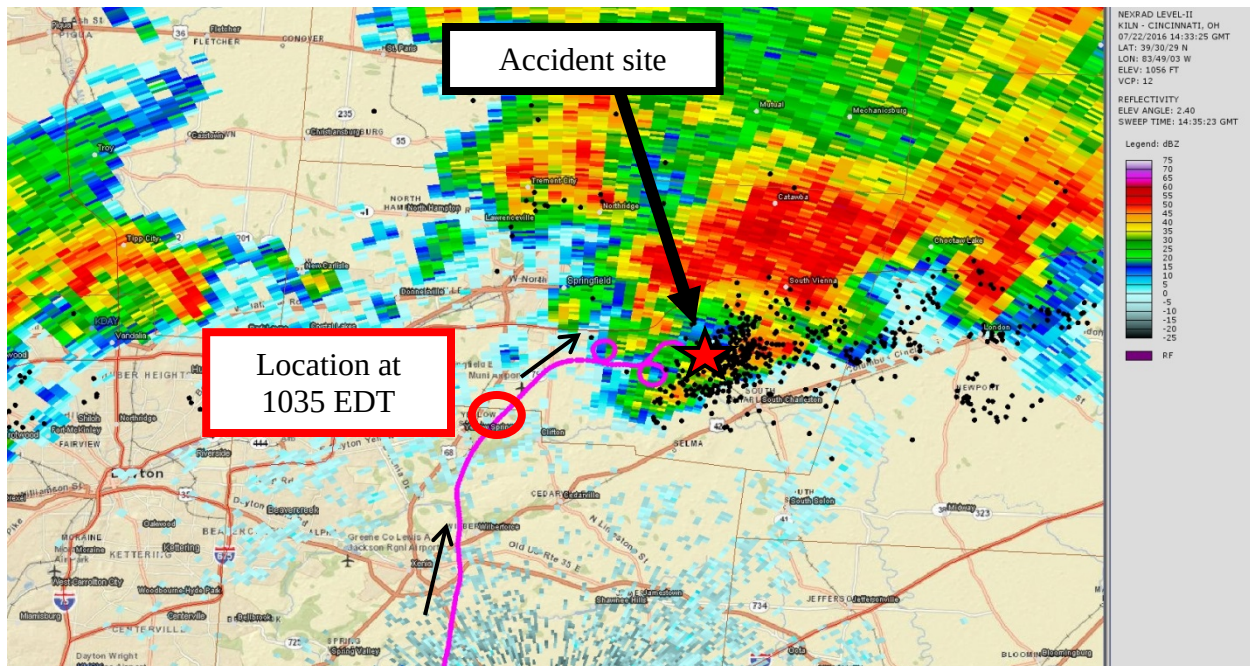


Figure 20 – KILN WSR-88D reflectivity for the 2.4° elevation scan initiated at 1035 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

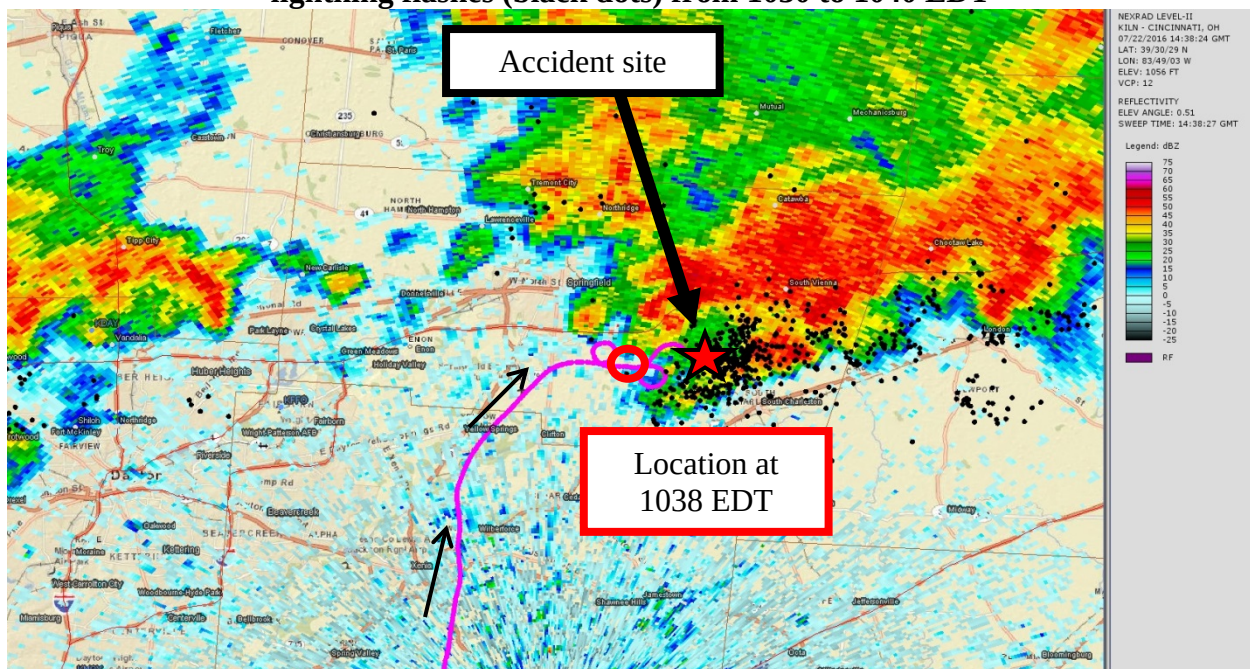


Figure 21 – KILN WSR-88D reflectivity for the 0.5° elevation scan initiated at 1038 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

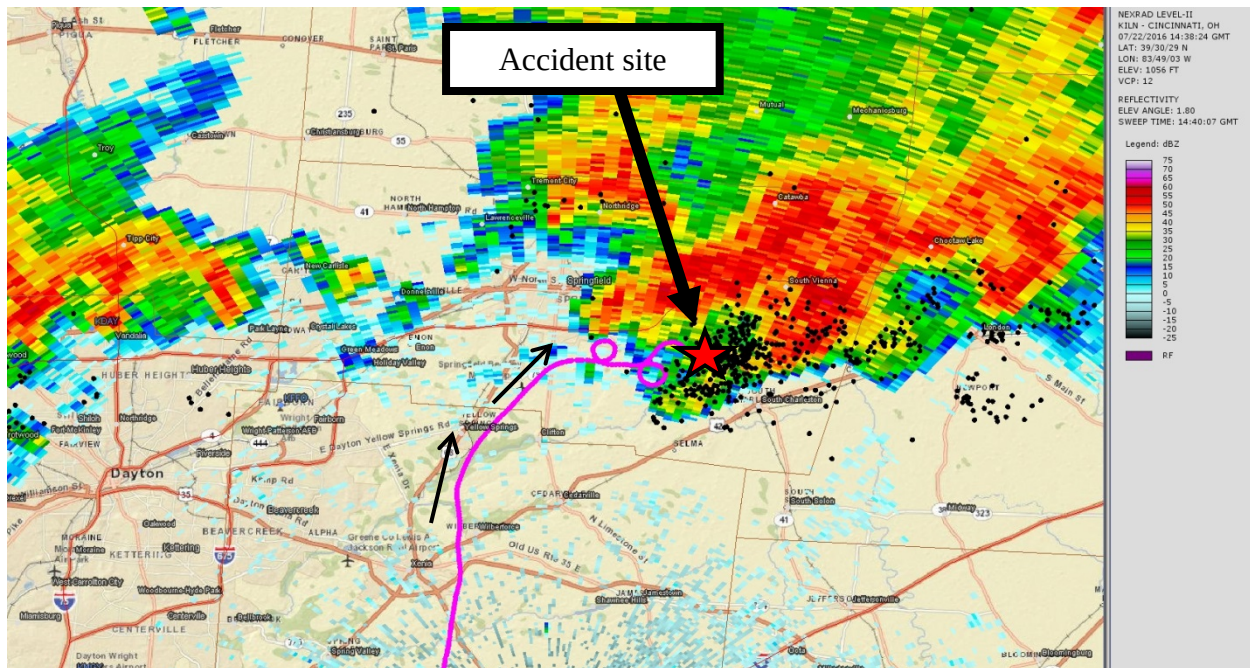


Figure 22 – KILN WSR-88D reflectivity for the 1.8° elevation scan initiated at 1040 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

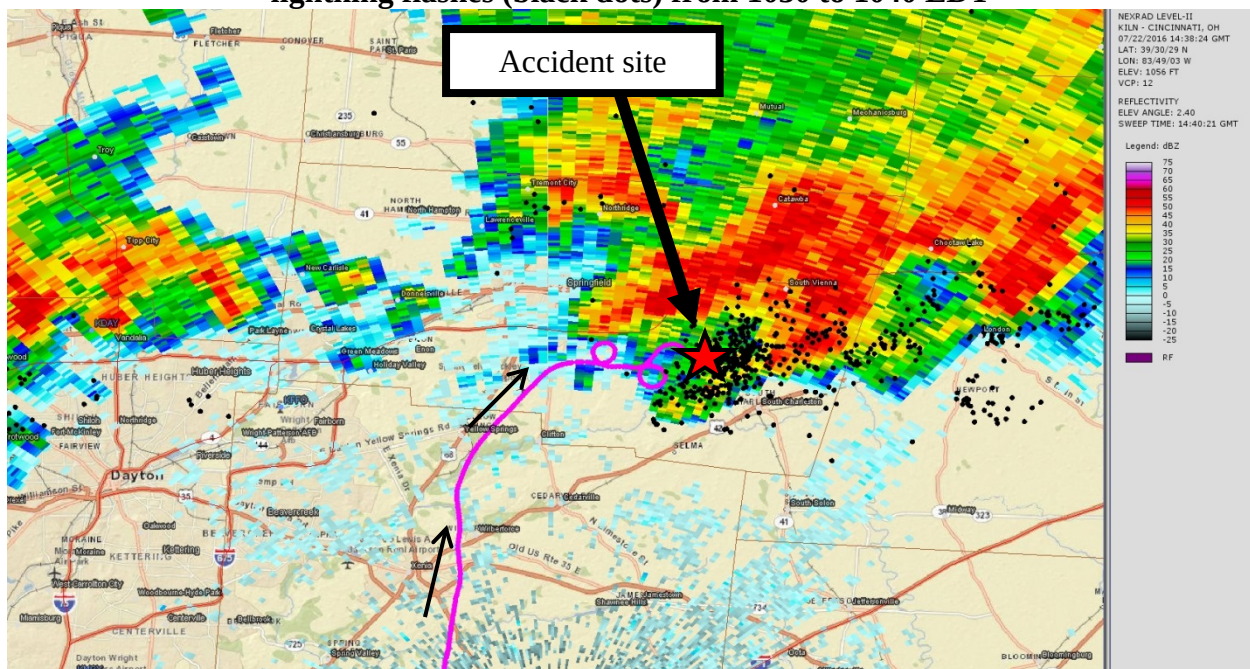


Figure 23 – KILN WSR-88D reflectivity for the 2.4° elevation scan initiated at 1040 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

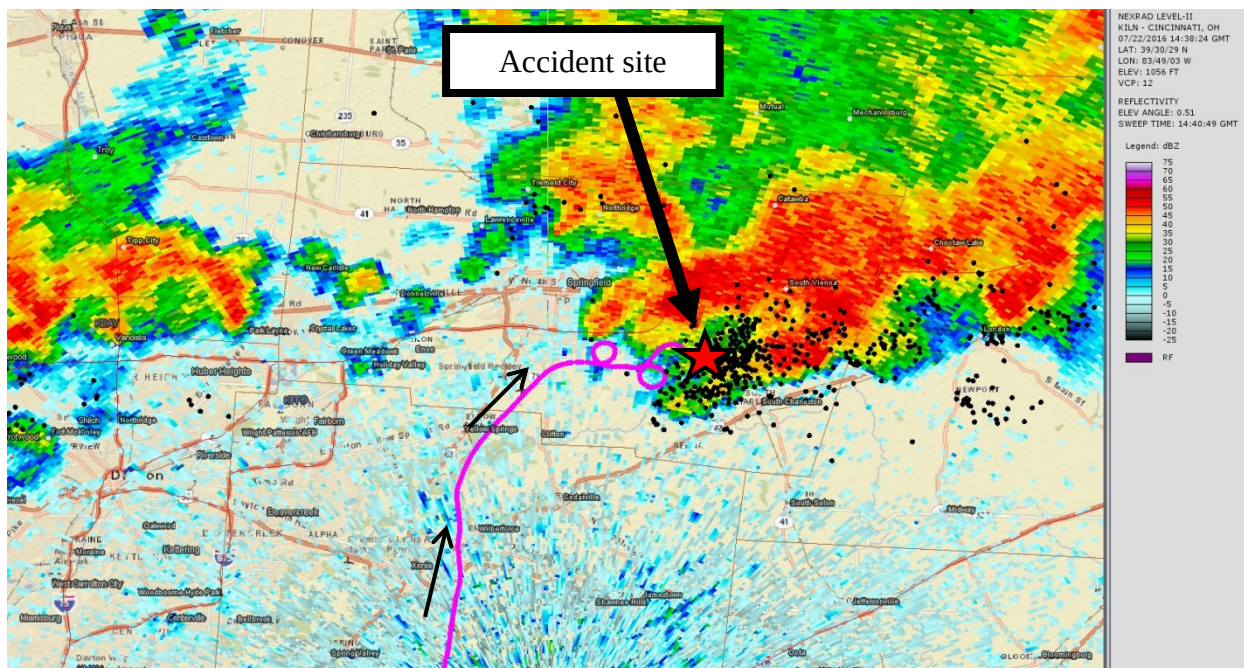


Figure 24 – KILN WSR-88D reflectivity for the 0.5° elevation scan initiated at 1041 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

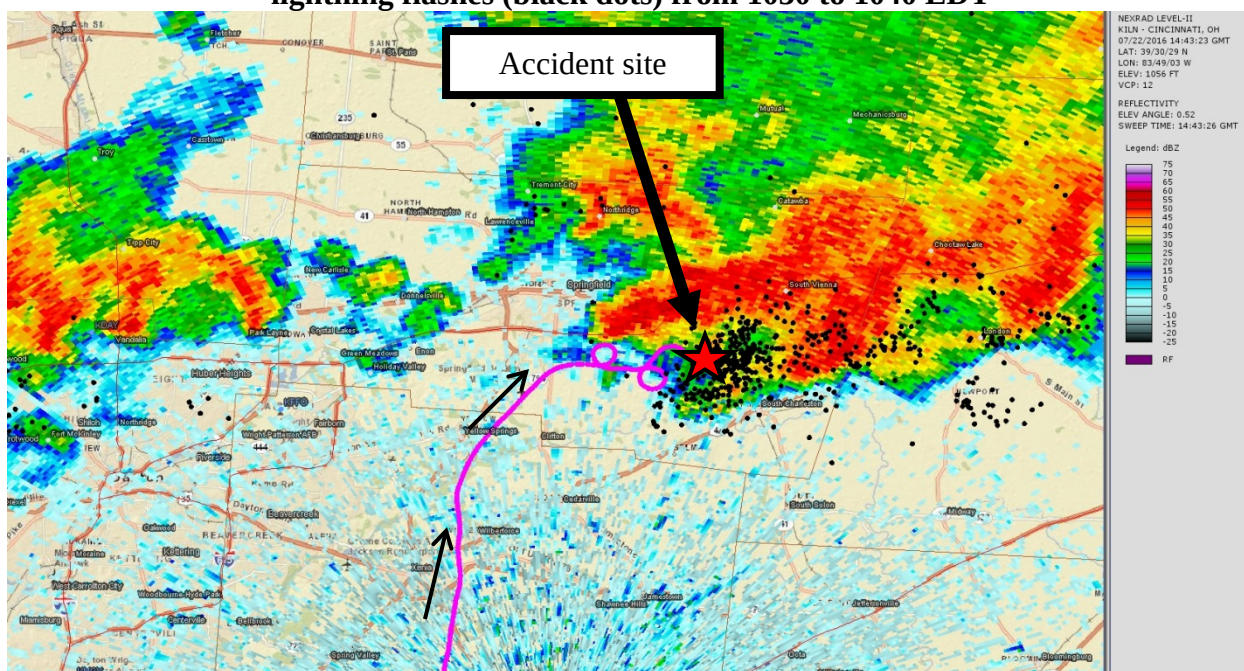


Figure 25 – KILN WSR-88D reflectivity for the 0.5° elevation scan initiated at 1043 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

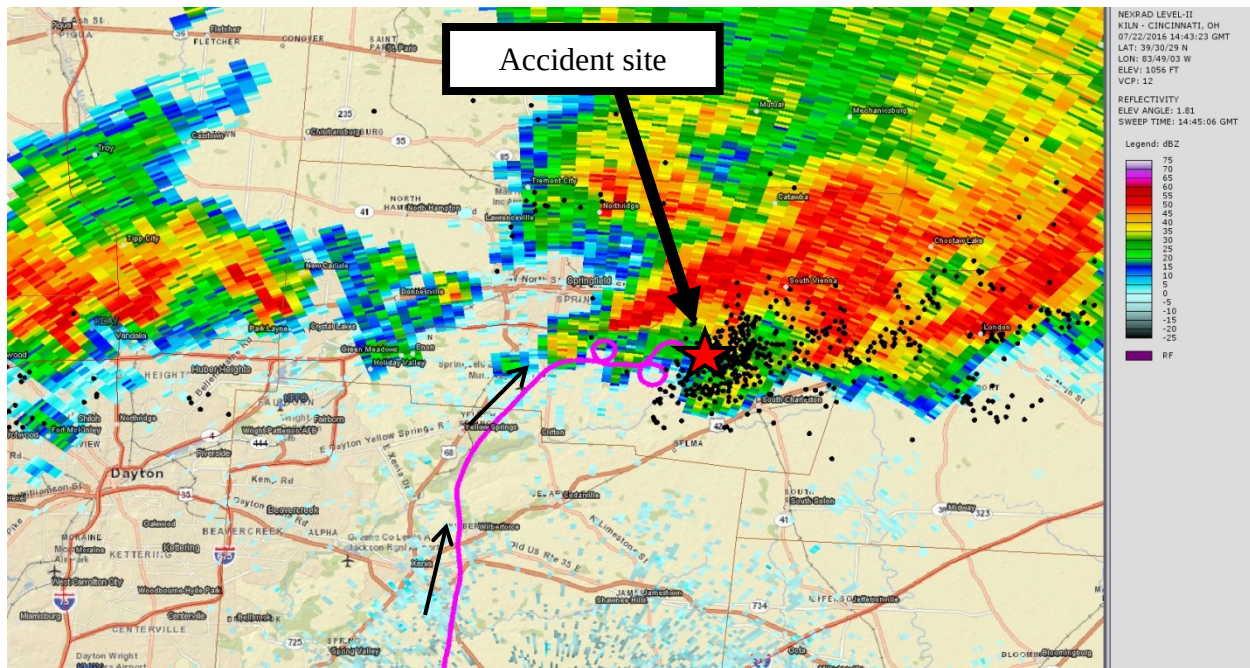


Figure 26 – KILN WSR-88D reflectivity for the 1.8° elevation scan initiated at 1045 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

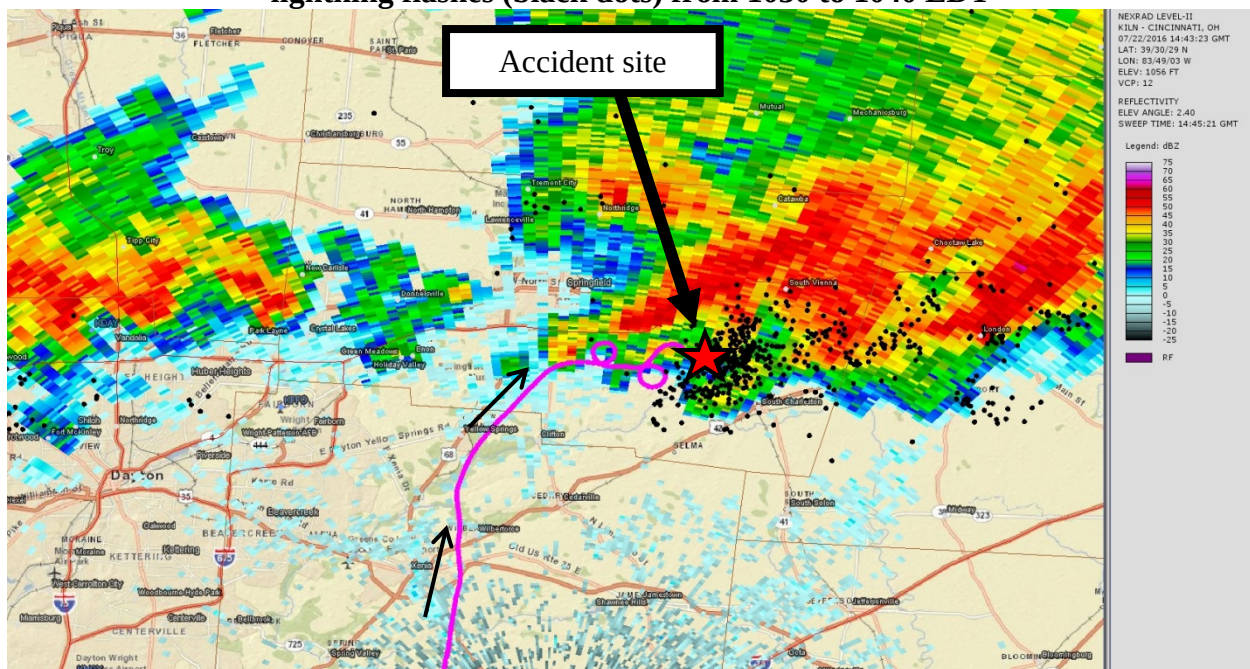


Figure 27 – KILN WSR-88D reflectivity for the 2.4° elevation scan initiated at 1045 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

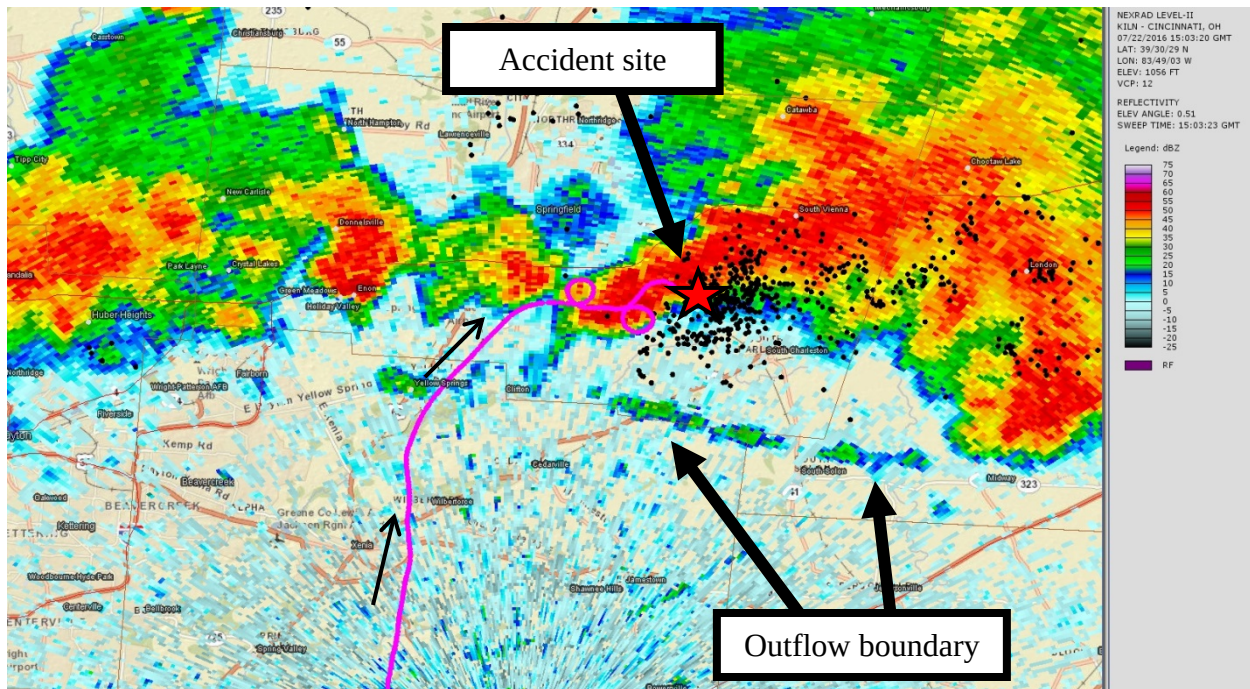


Figure 28 – KILN WSR-88D reflectivity for the 0.5° elevation scan initiated at 1103 EDT with the ATC flight track (pink dots) and arrows pointing in direction of travel and lightning flashes (black dots) from 1030 to 1040 EDT

6.6 3-Dimensional Radar Reflectivity Data

Figures 29, 30, and 31 present a 3-dimensional view of the KILN WSR-88D base reflectivity for the elevation scans initiated at 1038 EDT. The accident aircraft's flight track obtained from ATC²⁸ was also plotted on the Google Earth image for a time comparison with the base reflectivity images. The images indicated that the accident flight flew into an area of greater than 20 dBZ reflectivity values with greater than 34 dBZ values located above the accident flight's altitude at 1038 EDT.

²⁸ For more information see the ATC data contained in the docket for this accident.

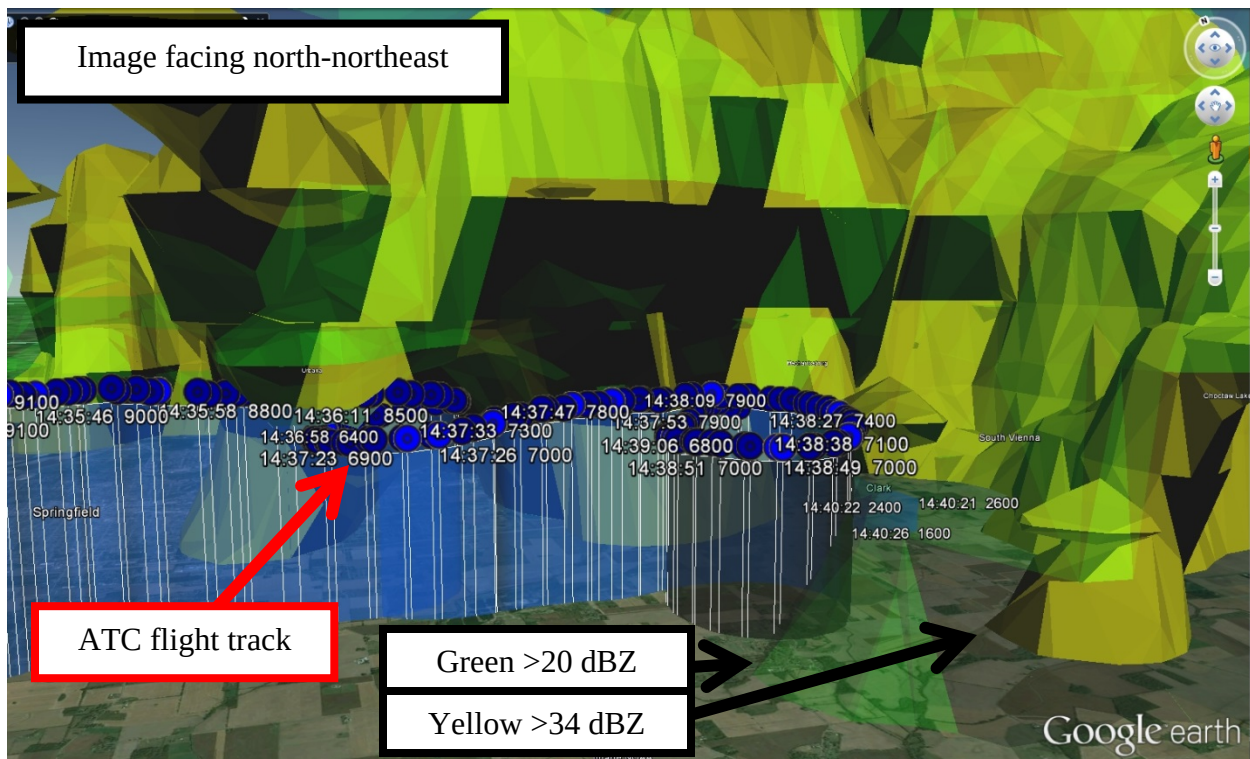


Figure 29 – 3-dimensional KILN WSR-88D base reflectivity from the scan initiated at 1038 EDT and the ATC Flight Track (blue dots) with the image facing north-northeast

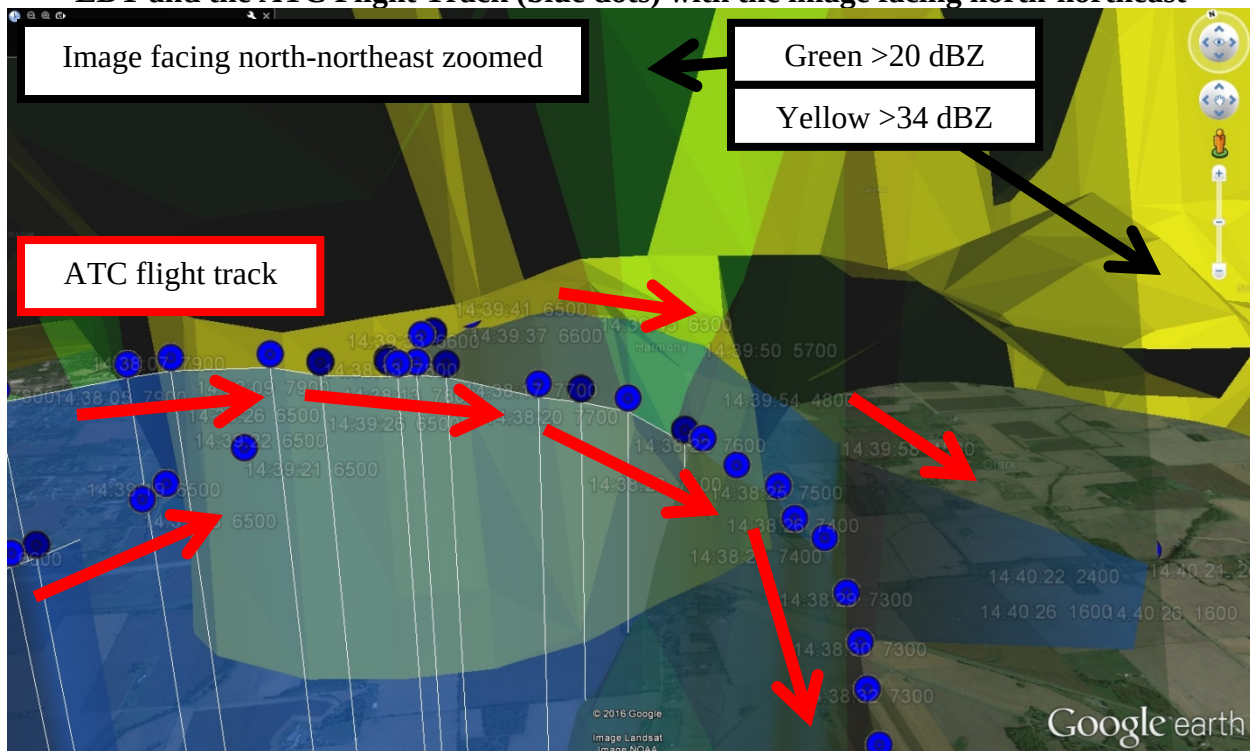


Figure 30 – 3-dimensional KILN WSR-88D base reflectivity from the scan initiated at 1038 EDT and the ATC Flight Track (red arrows for direction of travel) with the image facing north-northeast

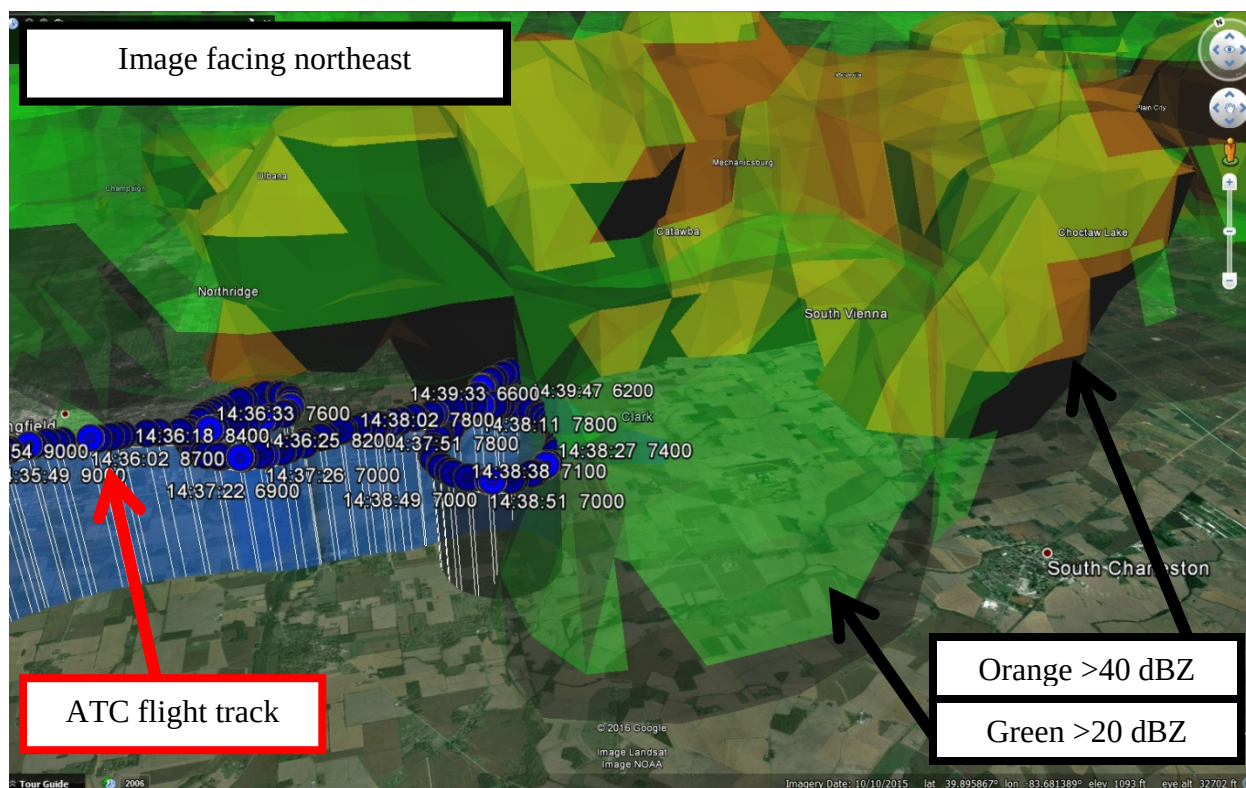


Figure 31 – 3-dimensional KILN WSR-88D base reflectivity from the scan initiated at 1038 EDT and the ATC Flight Track (blue dots) with the image facing northeast

7.0 Pilot Reports

All pilot reports (PIREPs) close to the accident site from about four hours prior to the accident time to about two hours after the accident time for below FL200²⁹ are provided below:

BMG UA /OV OOM090015/TM 1105/FL170/TP E170/TB LGT-MOD/RM TURBULENCE

BMG UA /OV OOM180040/TM 1110/FL175/TP E170/TB LGT-MOD 175-270

CVG UA /OV CVG315006/TM 1432/FL090/TP P28A/SK OVC100/TA 14/TB NEG/RM SMTH NO PCPN

MZZ UA /OV HHG200010/TM 1443/FL045/TP CH7A/SK FEW020/WX FV20SM/TB NEG/RM HI CIRRUS
ABV SMOOTH

LWB UA /OV ROA310023/TM 1526/FL080/TP BE36/WX FV99SM/WV 33028KT/TB NEG/RM SMOOTH

JKL UA /OV AZQ360010/TM 1530/FL090/TP P28A/SK SKC/TA 14/RM NEG PRECIPITATION

MZZ UA /OV FWA190024/TM 1554/FL080/TP BE36/SK FEW050/WX FV10SM/WV 30014KT/TB LGT CHOP

LEX UA /OV FLM2900015/TM 1603/FL195/TP E145/TA M3/IC LGT CLR 195-225

²⁹ 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 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); 15 miles from Bloomington, Indiana, on the 090° radial; Time – 0705 EDT (1105Z); Altitude – 17,000 feet msl; Type aircraft – Embraer ERJ-170; Turbulence – Light to moderate; Remarks – Turbulence.

Routine pilot report (UA); 40 miles from Bloomington, Indiana, on the 180° radial; Time – 0710 EDT (1110Z); Altitude – 17,500 feet msl; Type aircraft – Embraer ERJ-170; Turbulence – Light to moderate between 17,500 feet msl and FL270.

Routine pilot report (UA); 6 miles from Covington, Kentucky, on the 315° radial; Time – 1032 EDT (1432Z); Altitude – 9,000 feet msl; Type aircraft – Piper PA-28 Cherokee; Sky – Overcast ceiling at 10,000 feet msl; Temperature – 14° C; Turbulence – Negative; Remarks – Smooth with no precipitation.

Routine pilot report (UA); 10 miles from Huntington, Indiana, on the 200° radial; Time – 1043 EDT (1443Z); Altitude – 4,500 feet msl; Type aircraft – American Champion Citabria; Sky – Few clouds at 2,000 feet msl; Weather – Forward visibility 20 miles; Turbulence – Negative; Remarks – High cirrus above smooth.

Routine pilot report (UA); 23 miles from Roanoke, Virginia, on the 310° radial; Time – 1126 EDT (1526Z); Altitude – 8,000 feet msl; Type aircraft – Beechcraft Bonanza BE36; Weather – Forward visibility unlimited; Wind – From 330° at 28 knots; Turbulence – Negative; Remarks – Smooth.

Routine pilot report (UA); 10 miles from Hazard, Kentucky, on the 360° radial; Time – 1130 EDT (1530Z); Altitude – 9,000 feet msl; Type aircraft – Piper PA-28 Cherokee; Sky – Clear; Temperature – 14° C; Remarks – Negative precipitation.

Routine pilot report (UA); 24 miles from Fort Wayne, Indiana, on the 190° radial; Time – 1154 EDT (1554Z); Altitude – 8,000 feet msl; Type aircraft – Beechcraft Bonanza BE36; Sky – Few clouds at 5,000 feet msl; Weather – Forward visibility 10 miles; Wind – From 300° at 14 knots; Turbulence – Light chop.

Routine pilot report (UA); 15 miles from Falmouth, Kentucky, on the 290° radial; Time – 1203 EDT (1603Z); Altitude – 19,500 feet msl; Type aircraft – Embraer ERJ-145; Temperature – -3° C; Icing – Light clear between FL195 and FL225.

Routine pilot report (UA); 8 miles from Wilmington, Ohio, on the 180° radial; Time – 1208 EDT (1608Z); Altitude – 2,600 feet msl; Type aircraft – Boeing B767; Sky – Bases at 2,600 feet msl with ragged tops at 4,200 feet msl.

8.0 SIGMET and CWSU Advisory

Convective SIGMET 32E, issued at 0955 EDT, was valid for the accident site at the accident time. SIGMET 32E warned of an area of thunderstorms across central and southwest Ohio with tops above FL450 moving from 280° at 30 knots (figure 34). SIGMET 30E, issued at 0855 EDT, was also valid for the accident site at the accident time. SIGMET 30E also warned of thunderstorms across central and northeastern Ohio with tops above FL450 moving from 280° at 30 knots (figure 33). SIGMET 28E, issued at 0755 EDT, was issued before the second LMFS briefing received by the accident pilot (section 16.0), with the intended accident flight route passing through the extreme western edge of SIGMET 28E (figure 32). With the rain shower and thunderstorm activity continuing past 1100 EDT, more SIGMETs were issued for the accident area after the accident time (figure 35):

WSUS31 KPCI 221355

SIGE

_MKCE WST 221355

CONVECTIVE SIGMET 32E

VALID UNTIL 1555Z

OH IN

**FROM 50WSW CLE-40SSE CLE-30W AIR-20NNW CVG-40ENE IND-50WSW CLE
AREA TS MOV FROM 28030KT. TOPS ABV FL450.**

WSUS31 KPCI 221255

SIGE

_MKCE WST 221255

CONVECTIVE SIGMET 30E

VALID UNTIL 1455Z

PA WV OH LE

**FROM 20W ERI-20N SLT-30N JST-30SSW ROD-20NNE ROD-20W ERI
AREA TS MOV FROM 28030KT. TOPS ABV FL450.**

WSUS31 KPCI 221155

SIGE

_MKCE WST 221155

CONVECTIVE SIGMET 28E

VALID UNTIL 1355Z

NY PA OH LE

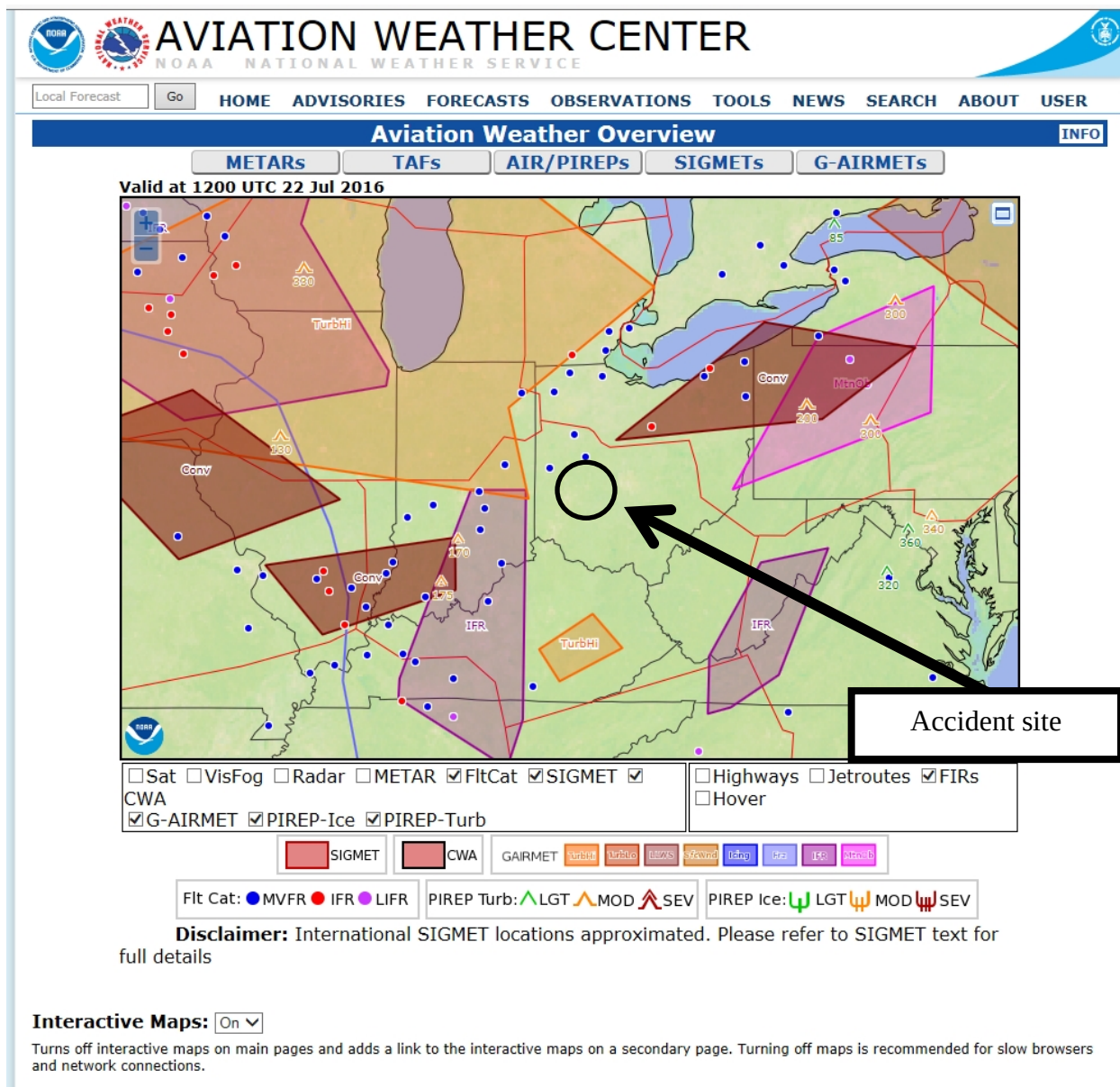
**FROM 20N ERI-40NE SLT-40NNW JST-40NW APE-20N ERI
AREA TS MOV FROM 28030KT. TOPS ABV FL450.**

Both the Center Weather Service Unit (CWSU) in Cleveland (ZOB) and the CWSU in Indianapolis (ZID) issued Meteorological Impact Statements (MIS) that were valid for the accident site at the accident time. No CWSU Advisories (CWA)s were valid for the accident site at the accident time. The MIS issued by ZID was issued at 0936 EDT and discussed that thunderstorms would form in short lines and clusters of thunderstorms from central Ohio and Indiana southward. The thunderstorm cells would move from 280° at 15 knots with thunderstorm tops above FL450. With the thunderstorm activity occasional moderate turbulence was expected from FL180 to FL430 in ZID airspace. The ZOB MIS issued at 0842 EDT mentioned thunderstorm activity in ZOB airspace with the thunderstorm movement from the northwest at 20 to 30 knots and tops above FL450. ZOB cloud ceilings were also expected to remain below 5,000 feet msl:

FAUS20 KZID 221336
ZID MIS 01 VALID 221340-230130
...FOR ATC PLANNING PURPOSES ONLY...
**IN ZID SOUTH OF A LINE 30N ROD-50NW PXV TS WILL FORM
SHORT LINES AND CLUSTERS. CELLS MOVE FROM 28015KT. MAX
TOPS ABV FL450. DUE CONVECTION OCNL MOD TURB FL180-430.**
=

FAUS20 KZOB 221242
ZOB MIS 01 VALID 221242-221800
...FOR ATC PLANNING PURPOSES ONLY...
**TROF MOV S FROM LK HURON. NMRS TS NW PA DCR TO SCT TS
MOV FROM NW 20-30KT. TOPS ABV FL450. ELSW WDLY SCT TS
OCNL FORM TO SCT COVERAGE. TS OCCUR AFT 15Z SE 1/8.
THRUT AREA CIG BLW 050.**
=

The accident pilot had access to review SIGMET 28E and its areal extent before takeoff, given that SIGMET 28E was issued before the second LMFS weather briefing (section 16.0). SIGMETs 30E and 32E were issued well before the accident time and covered the weather conditions experienced by the accident flight at the accident time. The accident pilot likely did not have access to the MIS issued by ZOB or ZID given that the MISs were issued after the second LMFS weather briefing (section 16.0). While the weather information contained in the MIS would be valuable for all pilots, the line at the top of the MIS "...FOR ATC PLANNING PURPOSES ONLY..." means that neither LMFS nor air traffic control will provide weather information contained in the MIS to pilots in their airspace. The Aviation Weather Center (AWC) does provide an access link to the CWSU MISs on their website.



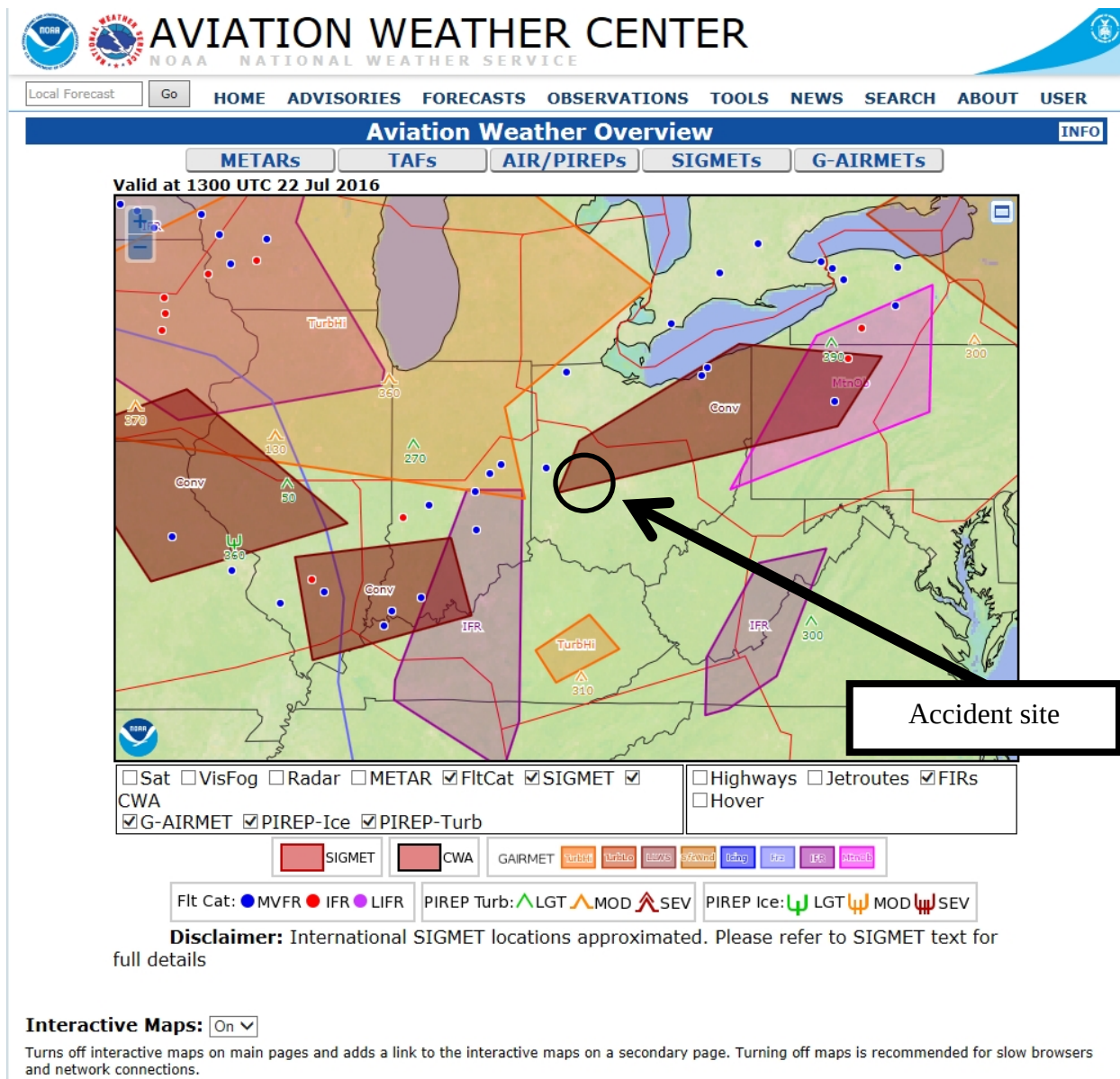


Figure 33 – AWC SIGMET, CWA, and AIRMET graphic valid for 0900 EDT

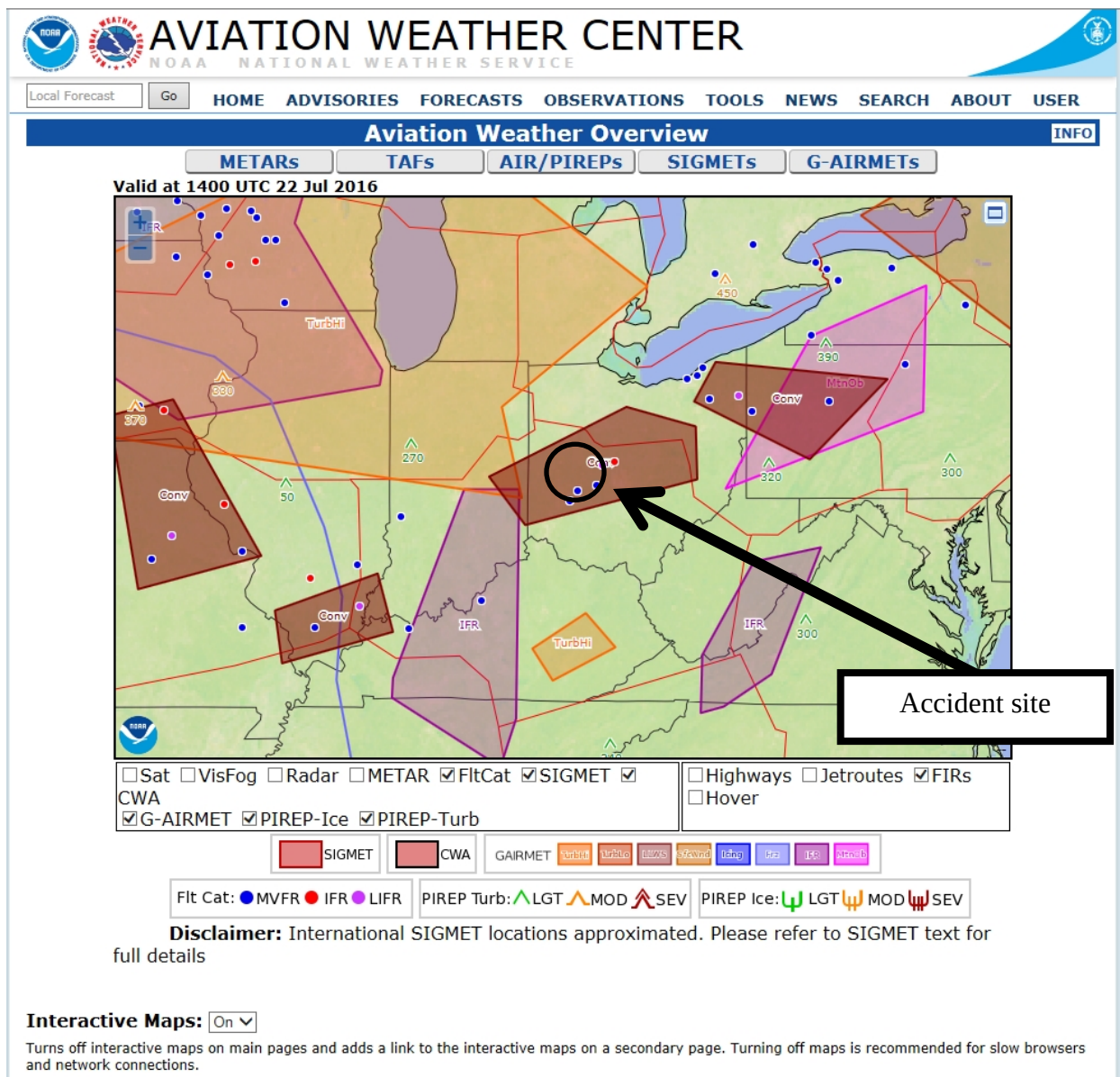
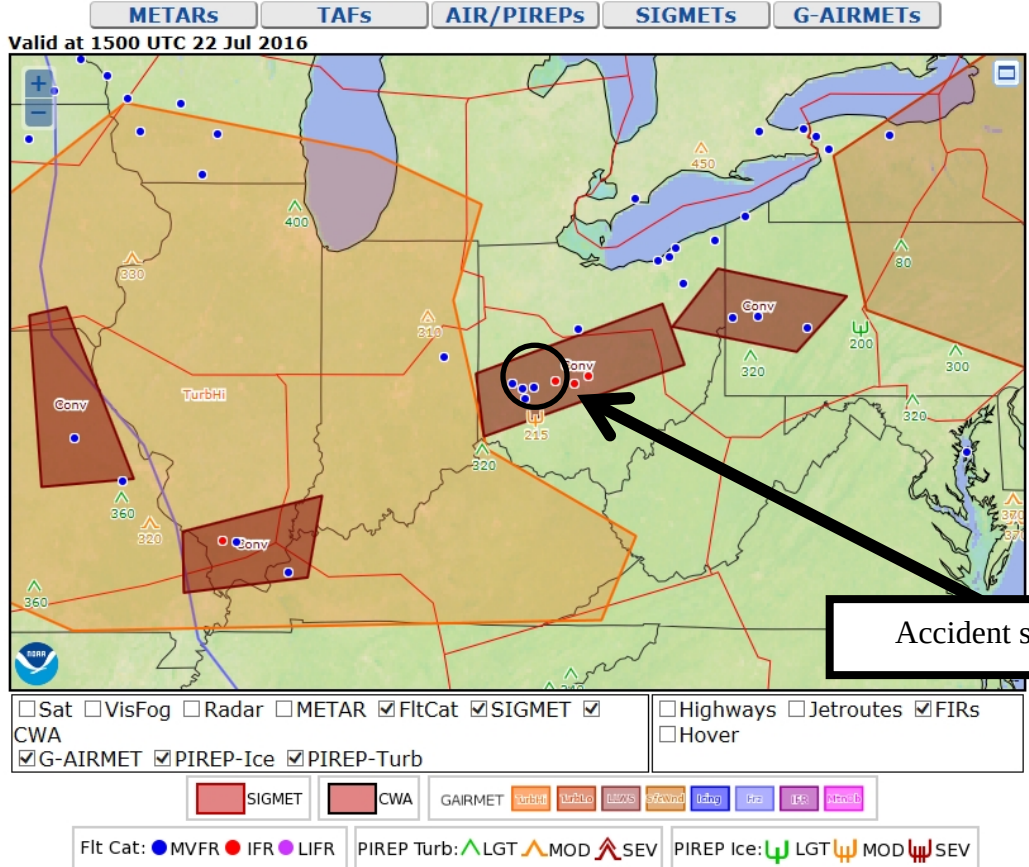


Figure 34 – AWC SIGMET, CWA, and AIRMET graphic valid for 1000 EDT



Collaborative Aviation Weather Statement 003
 NWS Aviation Weather Center Kansas City MO
 1109 UTC Fri 22 Jul 2016

Weather: Thunderstorms
 Valid: 1300-1500Z

ARTCCs affected: ZID, ZOB, ZNY
 Terminals affected:

CCFP: 11Z Issuance - Coverage/confidence too high

SUMMARY: High confidence sparse & medium coverage TS ZID/ZOB/ZNY

DISCUSSION: This CAWS refines CCFP 13-15Z for high confidence sparse & medium coverage TS srn IN/nrn KY-nrn PA. Current CCFP depicts broad area of medium coverage at 13Z with not enough sparse at 15Z. Expecting convection to persist beyond valid period.

Operations Note - CCFP areas that are not displayed in the CAWS graphic for the valid times posted are deemed to be accurate unless otherwise stated.

BOUNDING BOX: 34.12,-78.45 35.75,-91.86 44.68,-90.88 43.21,-74.90 34.12,-78.45

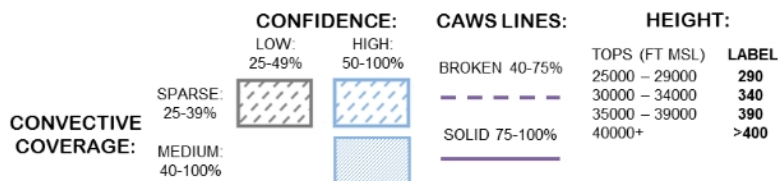


Figure 37 – CAWS 003 graphic valid for the accident site at the accident time with CCFP confidence and coverage intervals

10.0 AIRMETs

No AIRMETs were valid for the accident site at the accident time. The SIGMETs valid at the accident site at the accident time were appropriate and covered any AIRMET conditions that the accident flight could have experienced while in ZID airspace.

11.0 Area Forecast

The Area Forecast issued at 0445 EDT, valid at the accident time, forecasted scattered clouds between 4,000 and 6,000 feet between 1000 and 1300 EDT with isolated thunderstorms and light rain showers with cumulonimbus tops to FL410:

FAUS41 KPCI 220845
 FA1W
 _BOSC FA 220845
 SYNOPSIS AND VFR CLDS/WX
 SYNOPSIS VALID UNTIL 230300
 CLDS/WX VALID UNTIL 222100...OTLK VALID 222100-230300
 ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA AND CSTL WTRS
 .
 SEE AIRMET SIERRA FOR IFR CONDS AND MTN OBSCN.
 TS IMPLY SEV OR GTR TURB SEV ICE LLWS AND IFR CONDS.
 NON MSL HGTS DENOTED BY AGL OR CIG.
 .

SYNOPSIS...UPR LVL TROF WRN ME-VT NH WILL CONT EWD THRU PD.
SECONDARY TROF WILL APCH NRN NY 21-23Z AND WRN ME-NEW ENGLAND
THRU 03Z. HI PRES WILL DMNT THRUT RMNDR. WNW FLOW NRN PTN..NNW
FLOW SRN PTN. TROF NEW ENGLAND-E CNTRL US THRU PD. CDFNT WILL
APCH NRN NY-LO-LE 18-21Z AND WRN ME-NRN PTNS NH VT-CNTRL NY-NRN
OH LATE DURG OTLK.

.
ME
N HLF...SCT050 BKN130-150 LYRD FL240. ISOL SHRA/TSRA POSS SEV.
CB TOP FL360. BECMG 1517 BKN040 TOPS 120. WDLY SCT TSRA/SHRA.
TS POSS SEV. CB TOP FL380. OTLK...VFR SHRA TSRA.
S HLF...SCT150 BKN CI. BECMG 1618 SCT050. ISOL TSRA/SHRA. CB
TOP FL380. TS POSS SEV. OTLK...VFR SHRA TSRA.

.
NH VT
N HLF...SCT050-070. ISOL SHRA/TSRA POSS SEV. CB TOP FL380. 17Z
WDLY SCT TSRA/SHRA. TS POSS SEV. OTLK...VFR SHRA TSRA.
S HLF...SCT CI. BECMG 1517 SCT040-060. ISOL TSRA/SHRA. CB TOP
FL400. TS POSS SEV. OTLK...VFR SHRA TSRA.

.
MA RI CT
SCT CI. BECMG 1517 SCT045. ISOL TSRA/SHRA. TS POSS SEV. CB TOP
FL400. OTLK...VFR TSRA SHRA.

.
NY LO
SE NY-LONG ISLAND...SCT CI. BECMG 1517 SCT050. ISOL TSRA/SHRA.
TS POSS SEV. CB TOP FL400. OTLK...VFR SHRA TSRA.
NE NY...SCT045 SCT CI. ISOL TSRA/SHRA. CB TOP FL380. TS POSS
SEV. BECMG 1618 SCT060. ISOL TSRA/SHRA. TS POSS SEV.
OTLK...VFR SHRA TSRA.
CNTRL-WRN NY/LO...SCT035 SCT050. ISOL -SHRA/-TSRA. CB TOP FL380.
BECMG 1416 BKN035 TOPS 080. WDLY SCT TSRA/SHRA. TS POSS SEV.
CB TOP FL400. 18Z BKN040. WDLY SCT -TSRA/-SHRA. OTLK...VFR.

.
PA NJ
WRN-CNTRL PA...SCT050-070. ISOL -TSRA/-SHRA. CB TOP FL380. BECMG
1517 SCT045. ISOL -TSRA/-SHRA. CB TOP FL400. 20Z SCT-BKN045
TOPS 080. WDLY SCT -TSRA/-SHRA. OTLK...VFR.
ERN PA/NJ...SCT CI OCNL SKC. BECMG 1618 SCT050. ISOL
TSRA/SHRA. TS POSS SEV. CB TOP FL400. OTLK...VFR.

.
OH LE
NRN OH/LE...SCT040 SCT-BKN CI. ISOL -SHRA/-TSRA. CB TOP FL400.
BECMG 1417 BKN040 TOPS 080. WDLY SCT -SHRA/-TSRA. OTLK...VFR.
SRN OH...SCT050 BKN CI. BECMG 1417 SCT040-060. ISOL -TSRA/-SHRA.
CB TOP FL410. 20Z WDLY SCT -TSRA/-SHRA. OTLK...VFR SHRA TSRA.

.
WV
SCT CI. OCNL VIS 3-5SM BR. BECMG 1214 SCT060 SCT CI. 19Z
SCT050-070. ISOL -TSRA/-SHRA. CB TOP FL410. OTLK...VFR.

.
MD DC DE VA
NRN VA/WRN MD...SCT CI. OCNL SKC. BECMG 1618 SCT050. ISOL
-TSRA/-SHRA. CB TOP FL410. OTLK...VFR.
ERN MD/DC/DE...SKC OCNL SCT CI. BECMG 1618 SCT045. ISOL
-TSRA/-SHRA. CB TOP FL400. OTLK...VFR.

SWRN VA...SKC OCNL SCT CI. TIL 12Z OCNL VIS 3-5SM BR. BECMG 1618
SCT050. ISOL -TSRA/-SHRA. CB TOP FL400. OTLK...VFR.
SERN VA...SKC. SCT050 SCT CI. BECMG 1618 SCT040. ISOL
-TSRA/-SHRA. CB TOP FL410. OTLK...VFR TSRA.

.
CSTL WTRS
ACK-NWD...SCT CI. WND SW G25KT. BECMG 1719 SCT050. WND SW G30KT.
OTLK...VFR.
S ACK...SKC. BECMG 1618 SCT CI. OTLK...VFR.
....

12.0 Terminal Aerodrome Forecast

KFFO was the closest site to the accident site with a Terminal Aerodrome Forecast (TAF). The TAF valid at the time of the accident was issued at 1013 EDT and was valid for a 27-hour period beginning at 1000 EDT. The TAF for KFFO was as follows:³⁰

TAF AMD KFFO 221413Z 2214/2317 **23009KT 9000 -SHRA OVC030 QNH2998INS**
TEMPO 2214/2218 32010G25KT 4800 -TSRA OVC020CB
BECMG 2217/2218 25010G15KT 9999 NSW FEW040 QNH2994INS
TEMPO 2221/2224 24015G25KT 4800 TSRA OVC030CB
BECMG 2223/2224 21006KT 9999 SCT030 BKN050 QNH2993INS
TX31/2221Z TN22/2309Z=

The forecast expected a wind from 230° at 9 knots, 6 miles visibility, light rain showers, an overcast ceiling at 3,000 feet agl, and a minimum altimeter setting of 29.98 inches of mercury. Temporary conditions between 1000 and 1400 EDT were forecast with a wind from 320° at 10 knots with gusts to 25 knots, 3 miles visibility, thunderstorms and light rain, and an overcast ceiling at 2,000 feet agl.

James M Cox Dayton International Airport (KDAY) was the closest site to the accident site with a NWS TAF located 25 miles west of the accident site (figure 10). The KDAY TAF valid at the time of the accident was issued at 1021 EDT and was valid for a 22-hour period beginning at 1000 EDT. The TAF for KDAY was as follows:

TAF AMD KDAY 221421Z 2214/2312 **24011KT P6SM VCTS SCT040CB BKN200**
TEMPO 2214/2216 5SM -TSRA BR BKN020CB
FM230100 19004KT P6SM SCT250=

The forecast expected a wind from 240° at 11 knots, greater than 6 miles visibility, vicinity thunderstorms, a scattered cumulonimbus cloud layer at 4,000 feet agl, and a broken ceiling at 20,000 feet agl. Temporary conditions between 1000 and 1200 EDT were forecast with 5 miles visibility, thunderstorms and light rain, mist, and a broken ceiling at 2,000 feet agl with cumulonimbus clouds.

The latest KDAY TAF valid before the accident flight took off was issued at 0721 EDT and was valid for a 24-hour period beginning at 0800 EDT. The 0721 EDT TAF for KDAY was as follows:

³⁰ Military TAFs provide visibility forecast in meters rather than SM.

TAF KDAY 221121Z 2212/2312 19008KT P6SM OVC220
FM221400 24012KT P6SM VCTS SCT040CB BKN200
FM230100 19004KT P6SM SCT250=

The forecast expected a wind from 240° at 12 knots, greater than 6 miles visibility, vicinity thunderstorms, a scattered cumulonimbus cloud layer at 4,000 feet agl, and a broken ceiling at 20,000 feet agl.

13.0 NWS Area Forecast Discussion

The NWS Office in Wilmington, Ohio, issued the following Area Forecast Discussion (AFD) at 0931 EDT (closest AFD to the accident time). The aviation section of the AFD discussed that the computer weather models were not handling the current thunderstorm activity across central and southern Ohio very well. The timing of the thunderstorm activity moving over the TAF sites, if at all, was difficult to determine hence the “VCTS” wording in many of the TAFs. The surface wind was expected to remain out of the west to southwest under 12 knots:

FXUS61 KILN 221331

AFDILN

Area Forecast Discussion

National Weather Service Wilmington OH

931 AM EDT FRI JUL 22 2016

.SYNOPSIS...

An upper level ridge positioned over the nations mid section will continue to dominate the weather over the weekend before finally breaking down at the beginning of next week. this ridge will offer hot and humid weather conditions. The combination of heat and humidity will create heat index values above 100 degrees. This will result in period of storms to form through the weekend due to the high levels of moisture. The chance for precipitation increases early next week with the expected passage of a cold front.

&&

.NEAR TERM /UNTIL 6 PM THIS EVENING/...

Showers and thunderstorms have developed along a subtle boundary across parts of central and west-central Ohio early this morning. Expect that convection will increase as boundary shifts southeast through the morning and afternoon hours, especially as environment becomes increasingly unstable. To account for this, have raised PoPs across the area, with peak coverage expected during the afternoon.

There is some concern that with thick cirrus expanding eastward into area, combined with developing shower and thunderstorm activity, that high temps are too high for today. Nevertheless, with uncertainty in precip coverage and evolution, confidence didn't warrant making sweeping changes at this time. Therefore, have not made any changes to existing heat headlines.

&&

.SHORT TERM /6 PM THIS EVENING THROUGH SUNDAY/...

Possible ongoing MCS to start the evening expected to drop south-southeast across ILN/s FA and weaken this evening. Remainder of the night should be mainly dry but can not rule out stray pcpn.

Warm and humid conditions to continue with lows in the lower and middle 70s.

Difficult to pin point timing and placement of convection Saturday and Sunday. Have a mention of 40 percent both aftns with the best threat across the north closer to warm front. Heat continues with highs in the lower 90s on both Saturday and Sunday. Given high dewpoints...heat indices above 100 likely Saturday afternoon and possibly again Sunday. For now...have continue heat headlines for Saturday but these headlines may have to be extended into Sunday.

&&

.LONG TERM /SUNDAY NIGHT THROUGH THURSDAY/...

On Monday an upper level low will swing east across the Hudson Bay bringing a weak front across the area. Surface convergence is weak along the front and timing between the GFS and ECMWF is slightly out of phase. The ECMWF is slightly faster than the GFS with the GFS bringing the front through Tuesday morning. The ECMWF bring the front through Monday evening. Have leaned towards the ECMWF here.

Behind the front much drier air will filter in with PWATs less than 1.00". This will help to bring a temporary end in the precip until Thursday. At the end of extended Thursday another shortwave will approach the area bringing the chance of rain back to the area.

&&

.AVIATION /13Z FRIDAY THROUGH TUESDAY/...

Expect VFR to continue except at LUK where BR may reduce visibility early Saturday. **Otherwise, sky cover consists mainly of cirrus to start. Models are not handling current convection very well so forecast is more difficult than average.**

Thunderstorms to the west and northeast may not directly affect TAF sites. Additional convection may develop by afternoon peak heating so have included VCTS at all sites. Timing is hard to predict due to model uncertainty. Expect mainly clear skies after sunset as thunderstorms diminish with loss of daytime heating. Winds will generally be out of the west to southwest, with speeds 12 knots or less.

OUTLOOK...Thunderstorms possible Saturday through Monday.

&&

.ILN WATCHES/WARNINGS/ADVISORIES...

OH...Heat Advisory until 8 PM EDT Saturday for OHZ026-034-035-042>046-051>056-060-062>065-070>074-078>082-088.

Excessive Heat Warning until 8 PM EDT Saturday for OHZ061-077.

KY...Heat Advisory until 8 PM EDT Saturday for KYZ089>100.

IN...Heat Advisory until 8 PM EDT Saturday for INZ050-058-059-066-073>075-080.

&&

\$\$

14.0 NWS Special Weather Statement

The NWS Office in Wilmington, Ohio, issued Special Weather Statements (SPS)s at 1029 EDT, 1010 EDT, and as earlier as 0932 EDT warning of a line or cluster of strong thunderstorms (that the accident flight eventually encountered). The accident flight or air traffic control likely did not have had access to the SPS information unless the accident flight or air traffic control went directly to the NWS home page on a mobile or tablet device to view the SPS information. The convective SIGMETs issued and that were current at the accident time (section 8.0) covered the weather conditions contained in the SPSs:

WWUS81 KILN 221429
SPSILN
SPECIAL WEATHER STATEMENT
NATIONAL WEATHER SERVICE WILMINGTON OH
1029 AM EDT FRI JUL 22 2016

OHZ053-054-221500-
MADISON OH-CLARK OH-
1029 AM EDT FRI JUL 22 2016
...A STRONG THUNDERSTORM WILL AFFECT SOUTHWESTERN MADISON AND
SOUTHEASTERN CLARK COUNTIES UNTIL 1100 AM EDT...
AT 1029 AM EDT...RADAR INDICATED A STRONG THUNDERSTORM NEAR SOUTH
CHARLESTON...MOVING SOUTHEAST AT 20 MPH.
STORM HAZARDS INCLUDE...
WINDS TO 40 MPH...
ONE HALF INCH DIAMETER HAIL...
FREQUENT CLOUD TO GROUND LIGHTNING...
VERY HEAVY RAIN...
LOCATIONS IMPACTED INCLUDE...
LONDON...SOUTH CHARLESTON...LISBON...BRIGHTON...SOUTH VIENNA...SOUTH
SOLON...PLATTSBURG...NEWPORT IN MADISON COUNTY...NEWPORT IN ADAMS
COUNTY...PITCHIN...INTERSTATE 70 AT STATE ROUTE 56 AND SELMA.
THIS INCLUDES I-70 IN OHIO BETWEEN MILE MARKERS 64 AND 72.

DO NOT STAY IN THE OPEN NOR SEEK SHELTER UNDER TREES WHEN LIGHTNING
THREATENS. MOVE INDOORS WHEN A THUNDERSTORM APPROACHES.
WATER WILL POND ON ROADS AND MAY QUICKLY FILL ROADSIDE DITCHES AND
SMALL STREAMS.
RESIDENTS IN THESE AREAS SHOULD REMAIN ALERT. IF THIS STORM BECOMES
STRONGER...THEN A WARNING MAY BE NEEDED.
TO REPORT HAZARDOUS WEATHER CONDITIONS...GO TO OUR WEBSITE AT
WEATHER.GOV/ILN AND SUBMIT YOUR REPORT VIA SOCIAL MEDIA...WHEN YOU
CAN DO SO SAFELY.
LAT...LON 3998 8361 3990 8336 3971 8352 3971 8357
3975 8365 3978 8365 3978 8370 3983 8380
TIME...MOT...LOC 1429Z 296DEG 17KT 3987 8361
\$\$
BINAU

WWUS81 KILN 221410
SPSILN
SPECIAL WEATHER STATEMENT
NATIONAL WEATHER SERVICE WILMINGTON OH
1010 AM EDT FRI JUL 22 2016

OHZ053-221445-
CLARK OH-
1010 AM EDT FRI JUL 22 2016
...A STRONG THUNDERSTORM WILL AFFECT WESTERN CLARK COUNTY UNTIL 1045
AM EDT...
AT 1009 AM EDT...RADAR INDICATED A STRONG THUNDERSTORM 7 MILES
NORTHWEST OF SPRINGFIELD...MOVING SOUTHEAST AT 15 MPH.
STORM HAZARDS INCLUDE...
WINDS TO 40 MPH...
FREQUENT CLOUD TO GROUND LIGHTNING...

VERY HEAVY RAIN...
LOCATIONS IMPACTED INCLUDE...
SPRINGFIELD...ENON...NORTH HAMPTON...TREMONT CITY...DONNELSVILLE...
SNYDERVILLE...LAWRENCEVILLE...BUCK CREEK STATE PARK...
GREEN MEADOWS AND HOLIDAY VALLEY.
THIS INCLUDES I-70 IN OHIO BETWEEN MILE MARKERS 46 AND 57.

DO NOT STAY IN THE OPEN NOR SEEK SHELTER UNDER TREES WHEN LIGHTNING
THREATENS. MOVE INDOORS WHEN A THUNDERSTORM APPROACHES.
WATER WILL POND ON ROADS AND MAY QUICKLY FILL ROADSIDE DITCHES AND
SMALL STREAMS.

RESIDENTS IN THESE AREAS SHOULD REMAIN ALERT. IF THIS STORM BECOMES
STRONGER...THEN A WARNING MAY BE NEEDED.
TO REPORT HAZARDOUS WEATHER CONDITIONS...GO TO OUR WEBSITE AT
WEATHER.GOV/ILN AND SUBMIT YOUR REPORT VIA SOCIAL MEDIA...WHEN YOU
CAN DO SO SAFELY.

LAT...LON 4002 8376 3994 8369 3986 8379 3983 8394
3984 8394 3984 8395 3985 8397 3996 8399
3999 8397 4003 8391 4003 8383

TIME...MOT...LOC 1409Z 327DEG 7KT 3999 8390

\$\$

BINAU

WWUS81 KILN 221332

SPSILN

SPECIAL WEATHER STATEMENT

NATIONAL WEATHER SERVICE WILMINGTON OH

932 AM EDT FRI JUL 22 2016

OHZ045-046-052>056-221400-

LICKING OH-FRANKLIN OH-UNION OH-MADISON OH-CLARK OH-DELAWARE OH-
CHAMPAIGN OH-

932 AM EDT FRI JUL 22 2016

...A LINE OF THUNDERSTORMS WILL AFFECT NORTHERN LICKING... NORTHERN
FRANKLIN...SOUTHEASTERN UNION AND NORTHEASTERN MADISON COUNTIES IN
CENTRAL OHIO...NORTHEASTERN CLARK COUNTY IN WEST CENTRAL
OHIO...DELAWARE COUNTY IN CENTRAL OHIO AND SOUTHEASTERN CHAMPAIGN
COUNTIES IN WEST CENTRAL OHIO UNTIL 1000 AM EDT...

AT 930 AM EDT...RADAR INDICATED THUNDERSTORMS ALONG A LINE EXTENDING
FROM NEAR MOUNT VERNON TO EAST OF MARYSVILLE TO NEAR
MECHANICSBURG...MOVING EAST AT 20 MPH.

STORM HAZARDS INCLUDE...

WIND GUSTS TO 45 MPH POSSIBLE...

FREQUENT CLOUD TO GROUND LIGHTNING...

VERY HEAVY RAIN...

LOCATIONS IMPACTED INCLUDE...

NEWARK...DUBLIN...WESTERVILLE...DELAWARE...UPPER ARLINGTON...

HILLIARD...MARYSVILLE...WORTHINGTON...POWELL...JOHNSTOWN...SUNBURY...

PLAIN CITY...UTICA...MECHANICSBURG...CHOCTAW LAKE...POLARIS...

SHAWNEE HILLS...GALENA AND OSTRANDER.

THIS INCLUDES THE FOLLOWING INTERSTATES...

I-70 IN OHIO BETWEEN MILE MARKERS 69 AND 72.

I-71 IN OHIO BETWEEN MILE MARKERS 117 AND 138.

DO NOT STAY IN THE OPEN NOR SEEK SHELTER UNDER TREES WHEN LIGHTNING
THREATENS. MOVE INDOORS WHEN THUNDERSTORMS APPROACH.

WATER WILL POND ON ROADS AND MAY QUICKLY FILL ROADSIDE DITCHES AND

SMALL STREAMS.

RESIDENTS IN THESE AREAS SHOULD REMAIN ALERT. IF THESE STORMS BECOME STRONGER...THEN A WARNING MAY BE NEEDED.

TO REPORT HAZARDOUS WEATHER CONDITIONS...GO TO OUR WEBSITE AT WEATHER.GOV/ILN AND SUBMIT YOUR REPORT VIA SOCIAL MEDIA...WHEN YOU CAN DO SO SAFELY.

LAT...LON 4012 8219 4012 8281 3993 8354 3998 8375

4024 8331 4036 8286 4035 8275 4028 8275

4027 8248 4025 8248 4024 8220 4023 8218

TIME...MOT...LOC 1330Z 282DEG 17KT 4041 8254 4023 8323 4002 8360

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BINAU

15.0 Winds and Temperature Aloft Forecast

The NWS 1001 EDT and 0404 EDT Winds and Temperature Aloft forecasts valid for the accident flight are included below:

FBUS31 KWN0 221401

FD1US1

_DATA BASED ON 221200Z

VALID 221800Z FOR USE 1400-2100Z. TEMPS NEG ABV 24000

FT 3000 6000 9000 12000 18000 24000 30000 34000 39000

CMH 2508 2712+19 2716+13 2716+06 2917-07 3115-17 312430 314340 314652

CVG 2510 2710+18 2610+12 2614+06 2914-06 3312-15 312429 322940 303153

FBUS31 KWN0 220804

FD1US1

_DATA BASED ON 220600Z

VALID 221200Z FOR USE 0800-1500Z. TEMPS NEG ABV 24000

FT 3000 6000 9000 12000 18000 24000 30000 34000 39000

CMH 2820 2917+18 2914+11 2810+05 3214-07 3411-16 322331 313741 304652

CVG 2619 2612+18 2406+13 2906+07 3408-08 3410-16 342129 322240 293552

The accident site was in between the Columbus, Ohio, (CMH), and the Covington, Kentucky, (CVG) forecast points. The 0404 EDT CVG forecast indicated a wind at 3,000 feet from 260° at 19 knots, a wind at 6,000 feet from 260° at 12 knots with a temperature of 18° C, a wind at 9,000 feet from 240° at 6 knots with a temperature of 13° C, and a wind at 12,000 feet from 290° at 6 knots with a temperature of 7° C. The 1001 EDT CVG forecast indicated a wind at 3,000 feet from 250° at 10 knots, a wind at 6,000 feet from 270° at 10 knots with a temperature of 18° C, a wind at 9,000 feet from 260° at 10 knots with a temperature of 12° C, and a wind at 12,000 feet from 260° at 14 knots with a temperature of 6° C. The 0404 EDT CMH forecast indicated a wind at 3,000 feet from 280° at 20 knots, a wind at 6,000 feet from 290° at 17 knots with a temperature of 18° C, a wind at 9,000 feet from 290° at 14 knots with a temperature of 11° C, and a wind at 12,000 feet from 280° at 10 knots with a temperature of 5° C. The 1001 EDT CMH forecast indicated a wind at 3,000 feet from 250° at 8 knots, a wind at 6,000 feet from 270° at 12 knots with a temperature of 19° C, a wind at 9,000 feet from 270° at 16 knots with a

temperature of 13° C, and a wind at 12,000 feet from 270° at 16 knots with a temperature of 6° C.

16.0 Pilot Weather Briefing and Information

A search of official weather briefing sources, such as LMFS and Direct User Access Terminal Service (DUATS), revealed that the accident pilot did contact LMFS at 0619 EDT and 0804 EDT. During the first LMFS weather briefing at 0619 EDT, the weather briefer and accident pilot discussed a Convective SIGMET outlook which bordered the area (along the western edge of the attended flight track) and was valid through 1150 EDT. In addition, the accident pilot and weather briefer discussed an AIRMET for moderate turbulence was also current to the west of the destination airport (attachment 2), leaving as soon as possible for the destination airport, the current weather synopsis for the route of flight, current METARs, no PIREPs along route of flight, convective SIGMET 24E east of the intended route and thunderstorms currently approaching the Mansfield, Ohio, area, no indication if thunderstorm line approaching Mansfield, Ohio, was continuing to develop or not, anticipation that thunderstorms would continue to develop since there was a frontal boundary in the area, winds aloft (section 15.0), and that turbulence was likely approaching destination location.

During the second LMFS weather briefing at 0804 EDT, the weather briefer and the accident pilot discussed that rain had developed through northern portions of Ohio and was slowly moving east-southeast, that Convective SIGMET 28E (section 8.0, figure 32) had been issued for the route of flight and that the thunderstorms were moving southeastward towards the Columbus, Ohio, area, and that an AIRMET for higher level turbulence had been issued for the northern portion of the intended route of flight. They also discussed that additional Convective SIGMETs could be issued for Ohio northward during the accident flight, that deviations to the west would likely avoid SIGMET 28E, that the accident pilot would likely go direct OSU (Columbus, Ohio) then direct to destination airport from OSU, and flight service contact frequencies. For more information, please see attachments 5, 6, 7, and 8. There is no record of the accident pilot receiving or retrieving any other weather information before or during the accident flight using tablets or other devices in the accident cockpit.

17.0 Gust Front, Outflow, and Thunderstorm Training Information

The Federal Aviation Administration's (FAA) Advisory Circular AC 00-24C titled "Thunderstorms" issued in February 2013 is the primary basic training guide on thunderstorm hazards used for flight training guidance. Figure 38 is a cross section of a squall line thunderstorm from AC 00-24B (similar images in AC 00-24C) depicting the shelf cloud, gust front, and its related cold air outflow. The turbulence region of a gust front are identified from the leading edge or "nose", which would be marked by a sudden wind shift and increase in wind speed along with potentially moderate to severe turbulence up to 1,000 and occasionally to 3,000 feet agl. Multiple surges of cold dense air are typical results in individual strong gusts. Behind the "head" of the gust front, another area of turbulence is typically found near the "wake." This can cause wave formations with the density discontinuities between the warm and cold air masses resulting again in moderate to severe turbulence (figure 39). Gust fronts or outflow boundaries are often observed extending up to 15 miles from the main precipitation core of the

thunderstorm and can be seen in this case (figure 28). In addition, the outflow or gust front can help induce additional thunderstorm activity or enhance thunderstorm activity, updrafts, and downdrafts already occurring (attachment 9).³¹ The enhancement of the rain showers and thunderstorm activity is what likely what occurred near the accident site at the accident time in this accident given the weather radar information from KILN (attachments 2, 3, and 4).

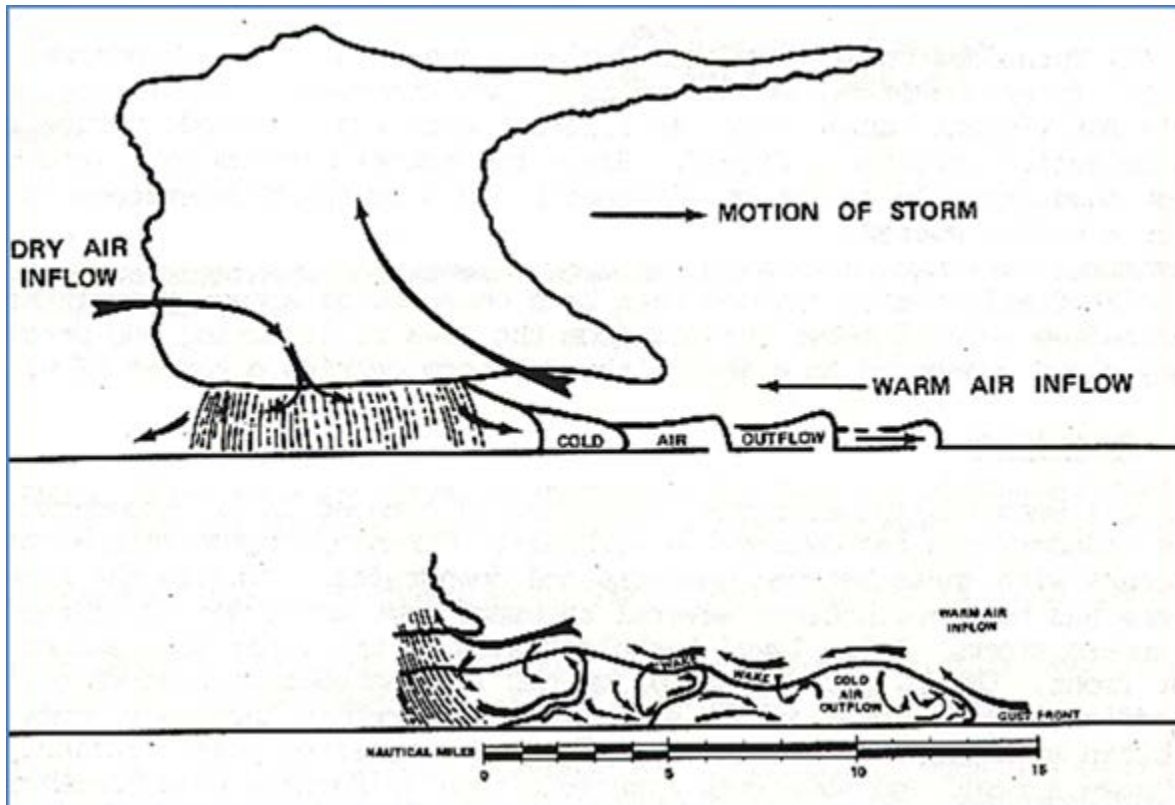


Figure 38 – Cross section of a thunderstorm showing the cold air outflow and gust front

As a result of the hazardous nature of thunderstorms and the related gust front and outflow the FAA has published several common practices or do's and don'ts on thunderstorm flying, which are published in AC 00-24C and the Aeronautical Information Manual (AIM) under Chapter 7 Safety of Flight, section 7-1-29. The following avoidance rules are published:

DOS AND DON'TS OF THUNDERSTORM AVOIDANCE.

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

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

³¹ http://glossary.ametsoc.org/wiki/Outflow_boundary

- (2) Don't attempt to fly under a thunderstorm even if you can see through to the other side. Turbulence and wind shear under the storm could be hazardous.
- (3) Don't attempt to fly under the anvil of a thunderstorm. There is a potential for severe and extreme clear air turbulence.
- (4) Don't fly without airborne radar into a cloud mass containing scattered embedded thunderstorms. Scattered thunderstorms not embedded usually can be visually circumnavigated.
- (5) Don't trust the visual appearance to be a reliable indicator of the turbulence inside a thunderstorm.
- (6) Don't assume that ATC will offer radar navigation guidance or deviations around thunderstorms.
- (7) Don't use data-linked weather next generation weather radar (NEXRAD) mosaic imagery as the sole means for negotiating a path through a thunderstorm area (tactical maneuvering).
- (8) Do remember that the data-linked NEXRAD mosaic imagery shows where the weather *was*, not where the weather *is*. The weather conditions may be 15 to 20 minutes older than the age indicated on the display.
- (9) Do listen to chatter on the ATC frequency for Pilot Weather Reports (PIREP) and other aircraft requesting to deviate or divert.
- (10) Do ask ATC for radar navigation guidance or to approve deviations around thunderstorms, if needed.
- (11) Do use data-linked weather NEXRAD mosaic imagery (e.g., Flight Information Service-Broadcast (FIS-B)) for route selection to avoid thunderstorms entirely (strategic maneuvering).
- (12) Do advise ATC, when switched to another controller, that you are deviating for thunderstorms before accepting to rejoin the original route.
- (13) Do ensure that after an authorized weather deviation, before accepting to rejoin the original route, that the route of flight is clear of thunderstorms.
- (14) Do avoid by at least 20 miles any thunderstorm identified as severe or giving an intense radar echo. This is especially true under the anvil of a large cumulonimbus.
- (15) Do circumnavigate the entire area if the area has 6/10 thunderstorm coverage.
- (16) Do remember that vivid and frequent lightning indicates the probability of a severe thunderstorm.
- (17) Do regard as extremely hazardous any thunderstorm with tops 35,000 feet or higher whether the top is visually sighted or determined by radar.
- (18) Do give a PIREP for the flight conditions.
- (19) Do divert and wait out the thunderstorms on the ground if unable to navigate around an area of thunderstorms.

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

- (1) Tighten the safety belt, put on the shoulder harness (if installed), and secure all loose objects.
- (2) Plan and hold the course to take the aircraft through the storm in a minimum time.
- (3) To avoid the most critical icing, establish a penetration altitude below the freezing level or above the level of -15°C.
- (4) Verify that pitot heat is on and turn on carburetor heat or jet engine anti-ice. Icing can be rapid at any altitude and cause almost instantaneous power failure and/or loss of airspeed indication.
- (5) Establish power settings for turbulence penetration airspeed recommended in the aircraft manual.
- (6) Turn up cockpit lights to highest intensity to lessen temporary blindness from lightning.
- (7) If using automatic pilot, disengage Altitude Hold Mode and Speed Hold Mode. The automatic altitude and speed controls will increase maneuvers of the aircraft thus increasing structural stress.
- (8) If using airborne radar, tilt the antenna up and down occasionally. This will permit the detection of other thunderstorm activity at altitudes other than the one being flown.

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

- (1) Do keep your eyes on the flight instruments. Looking outside the cockpit can increase danger of temporary blindness from lightning.
- (2) Don't change power settings; maintain settings for the recommended turbulence penetration airspeed.
- (3) Do maintain constant attitude. Allow the altitude and airspeed to fluctuate.
- (4) Don't turn back once in the thunderstorm. A straight course through the storm most likely will get the aircraft out of the hazards most quickly. In addition, turning maneuvers increase stress on the aircraft.

Figure 39 is a series of images from a research weather computer model simulating the turbulence flow created by the density differences in a gust front and the creation of Kelvin-Helmholtz instability³² along the boundary of the air mass. The turbulence noted along and in the gust front is a common location of loss of aircraft control.

³² Kelvin-Helmholtz instability – Instability caused by air masses with different densities moving at different speeds that create turbulence and wave-like patterns in the clouds when visible.

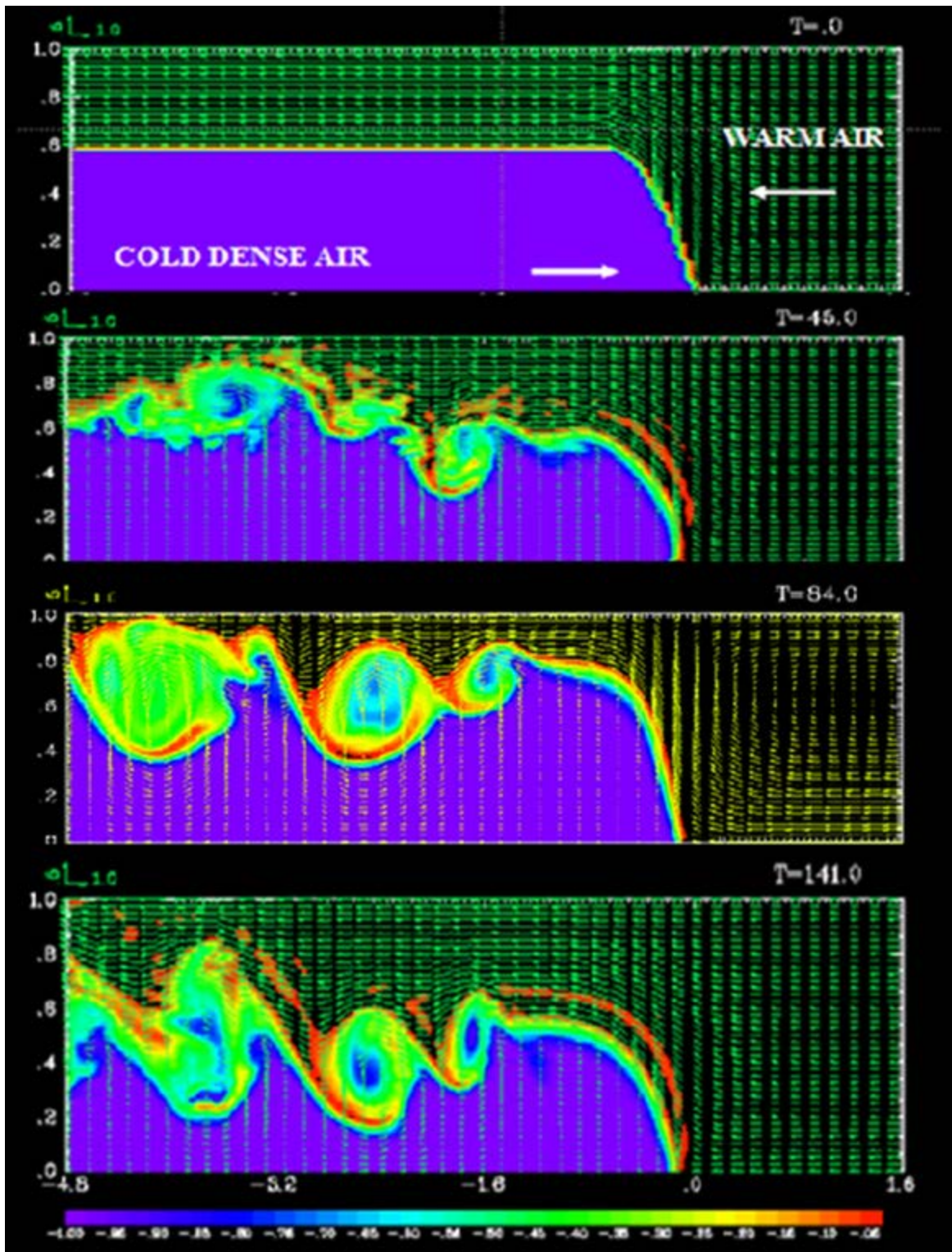


Figure 39 – Computer modeling of the turbulence flow created by the density differences in a gust front

18.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on July 22, 2016, indicated the following:

SUN

Begin civil twilight	0554 EDT
Sunrise	0625 EDT
Sun transit	1342 EDT
Sunset	2058 EDT
End civil twilight	2129 EDT

F. LIST OF ATTACHMENTS

Attachment 1 – GOES-13 visible satellite animation from 0745 to 1200 EDT

Attachment 2 – KILN WSR-88D reflectivity for the 0.5° elevation scan animation from 1009 EDT to 1103 EDT with the ATC flight track (pink dots) and lightning flashes (black dots)

Attachment 3 – KILN WSR-88D reflectivity for the 1.8° elevation scan animation from 1010 EDT to 1105 EDT with the ATC flight track (pink dots) and lightning flashes (black dots)

Attachment 4 – KILN WSR-88D reflectivity for the 2.4° elevation scan animation from 1010 EDT to 1105 EDT with the ATC flight track (pink dots) and lightning flashes (black dots)

Attachment 5 – LMFS weather briefing text information from 0619 EDT

Attachment 6 – LMFS weather briefing text information from 0804 EDT

Attachment 7 – LMFS weather briefing audio from 0619 EDT

Attachment 8 – LMFS weather briefing audio from 0804 EDT

Attachment 9 – Convective Initiation via Outflow Boundary Interaction with Quasi-stationary Thermal Circulations

Submitted by:

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