NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

April 21, 2017

Weather Study

METEOROLOGY

CEN17FA072

Table Of Contents

A. ACCIDENT

Location: Near Cleveland, Ohio
Date: December 29, 2016
Time: 2258 eastern standard time
0358 Coordinated Universal Time (UTC), December 30, 2016
Airplane: Cessna 525, N614SB

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 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 standard time (EST) on December 29, 2016, and are based upon the 24-hour clock, where local time is -5 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 41.537° N, longitude 81.714° W.

D. WEATHER INFORMATION

1.0 Synoptic Situation

The synoptic or large scale migratory weather systems influencing the area were documented using standard NWS charts issued by the National Center for Environmental Prediction and the Weather Prediction Center, located in College Park, Maryland. These are the base products used in describing synoptic weather features and in the creation of forecasts and warnings for the NWS. Reference to these charts can be found in the joint NWS and Federal Aviation Administration (FAA) Advisory Circular "Aviation Weather Services", AC 00-45H.

1.1 Surface Analysis Chart

The NWS Surface Analysis Chart for 2200 EST is provided as figure 1 with the approximate location of the accident site marked within the red circle. The chart depicted a surface trough[1] stretching from Quebec southwestward into Lake Huron, extreme northern Michigan, and across Lake Michigan. A surface low pressure system was located east of Maine in the northwestern Atlantic Ocean with a pressure of 981-hectopascals (hPa) associated with an occluded frontal system. The station models around the accident site depicted air temperatures in the mid to low 30's degrees Fahrenheit (°F), dew point temperatures in the upper 20's °F, a west wind between 10 and 20 knots, and cloudy skies with light snow.

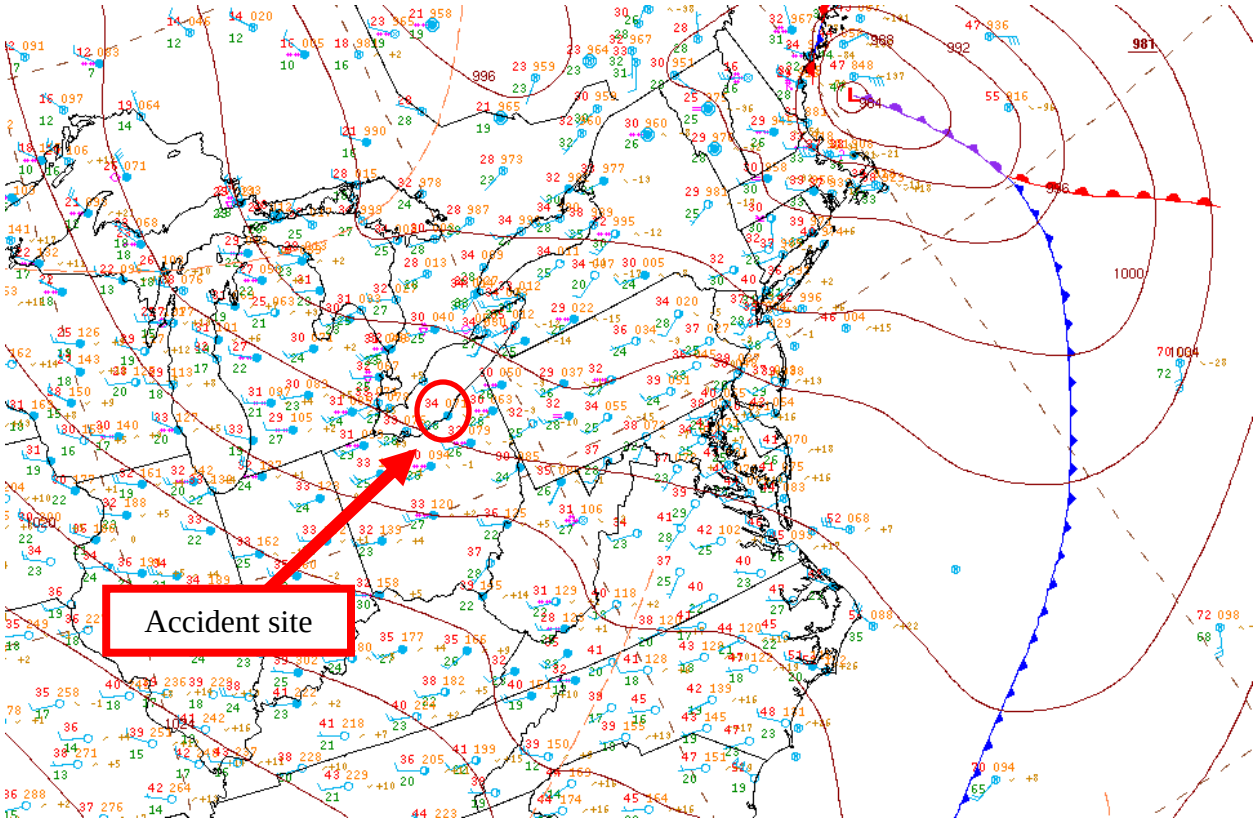

Figure 1 – NWS Surface Analysis Chart for 2200 EST

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

1.2 Upper Air Charts

The NWS Storm Prediction Center (SPC) Constant Pressure Charts for 1900 EST at 925-, 850-, 700-, 500-, and 300-hPa are presented in figures 2 through 6. The accident site was located in between low- and mid-level troughs at 925-, through 500-hPa (figures 2, 3, 4, and 5). Areas near troughs are favored locations for enhanced vertical motion, clouds, and precipitation. There was a west-southwest wind of 30 knots at 925-hPa (figure 2). The wind became westerly by 850- and 700-hPa and the wind speed increased to 40 knots (figures 3 and 4). By 500-hPa, the wind was still from the west, now at 45 knots (figure 5), with the wind speed increasing to 55 knots by 300-hPa (figure 6). The wind near the surface and up to 700-hPa was blowing from Lake Erie into north central Ohio and given the time of year and the colder air moving over the relatively warmer lake water, lake effect snow showers were favored. Section 17.0 will further discuss lake effect snow and its environment.

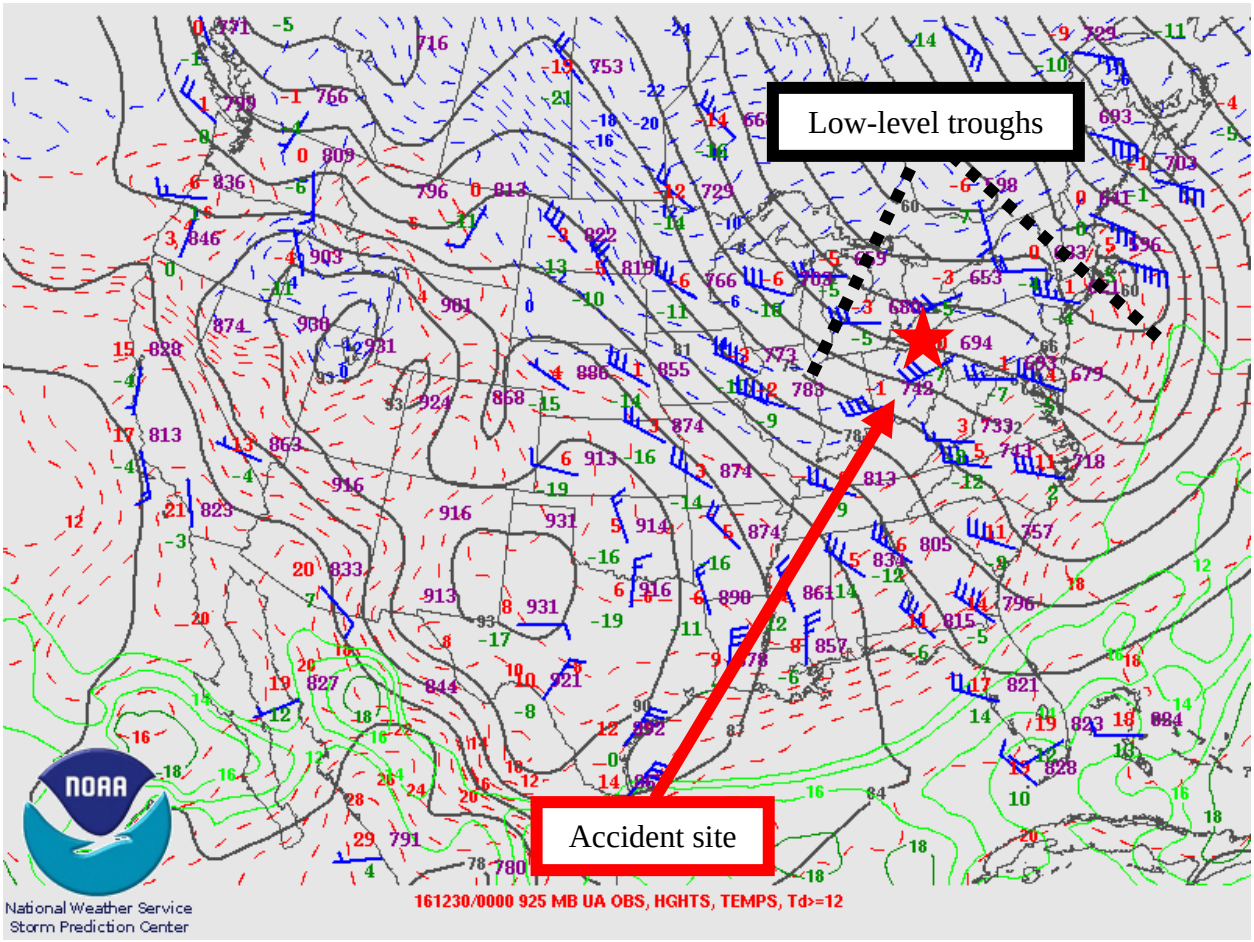

Figure 2 – 925-hPa Constant Pressure Chart for 1900 EST

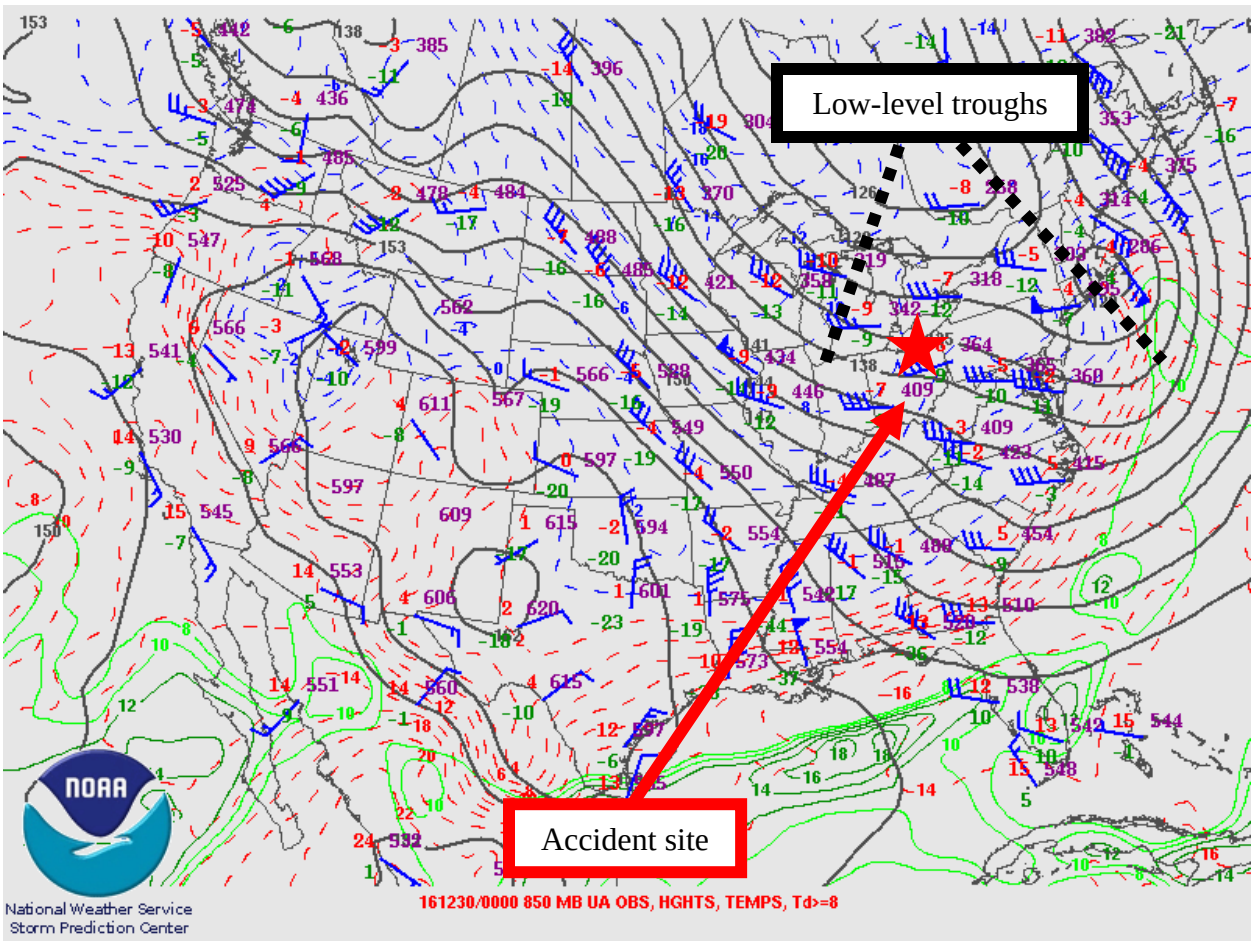

Figure 3 – 850-hPa Constant Pressure Chart for 1900 EST

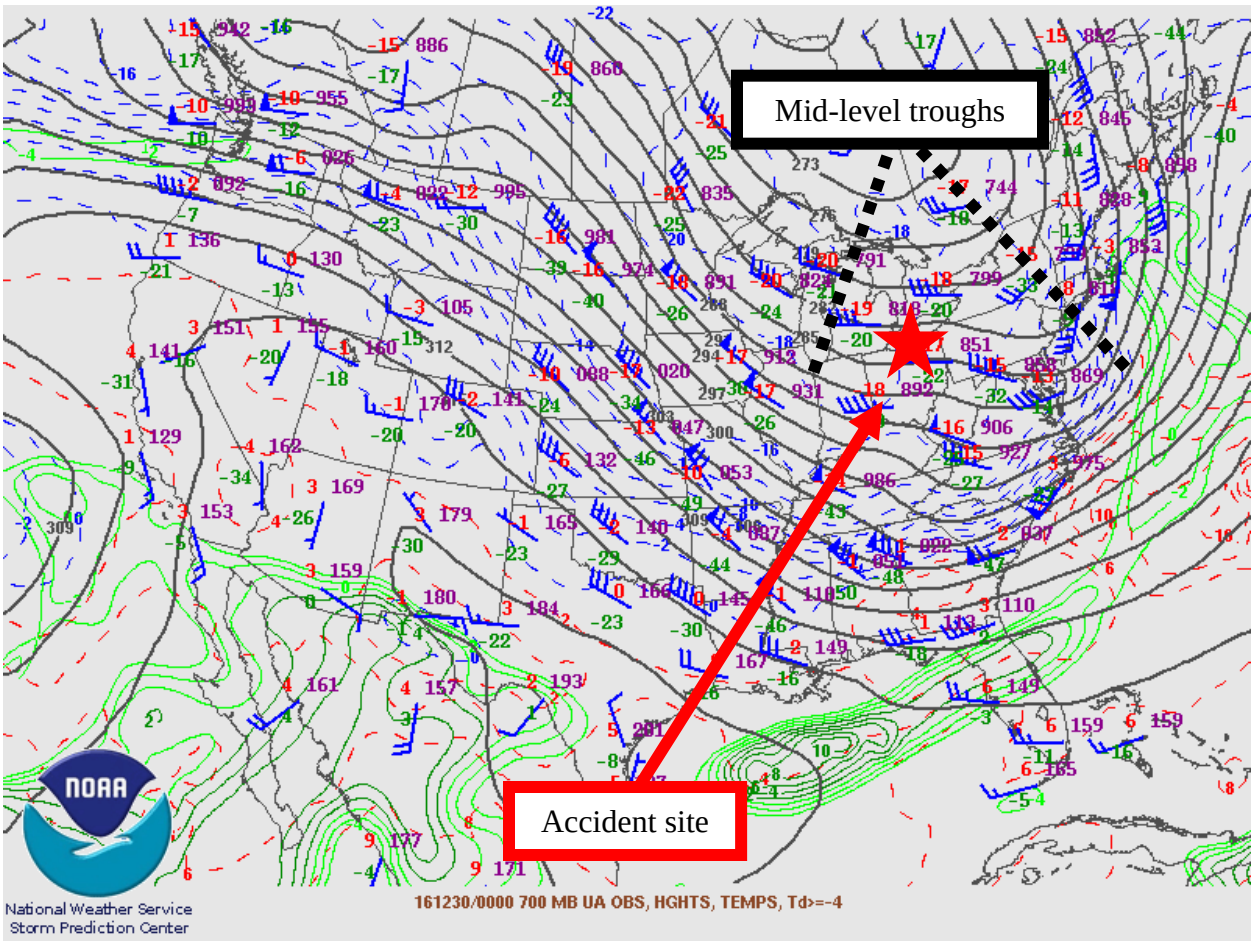

Figure 4 – 700-hPa Constant Pressure Chart for 1900 EST

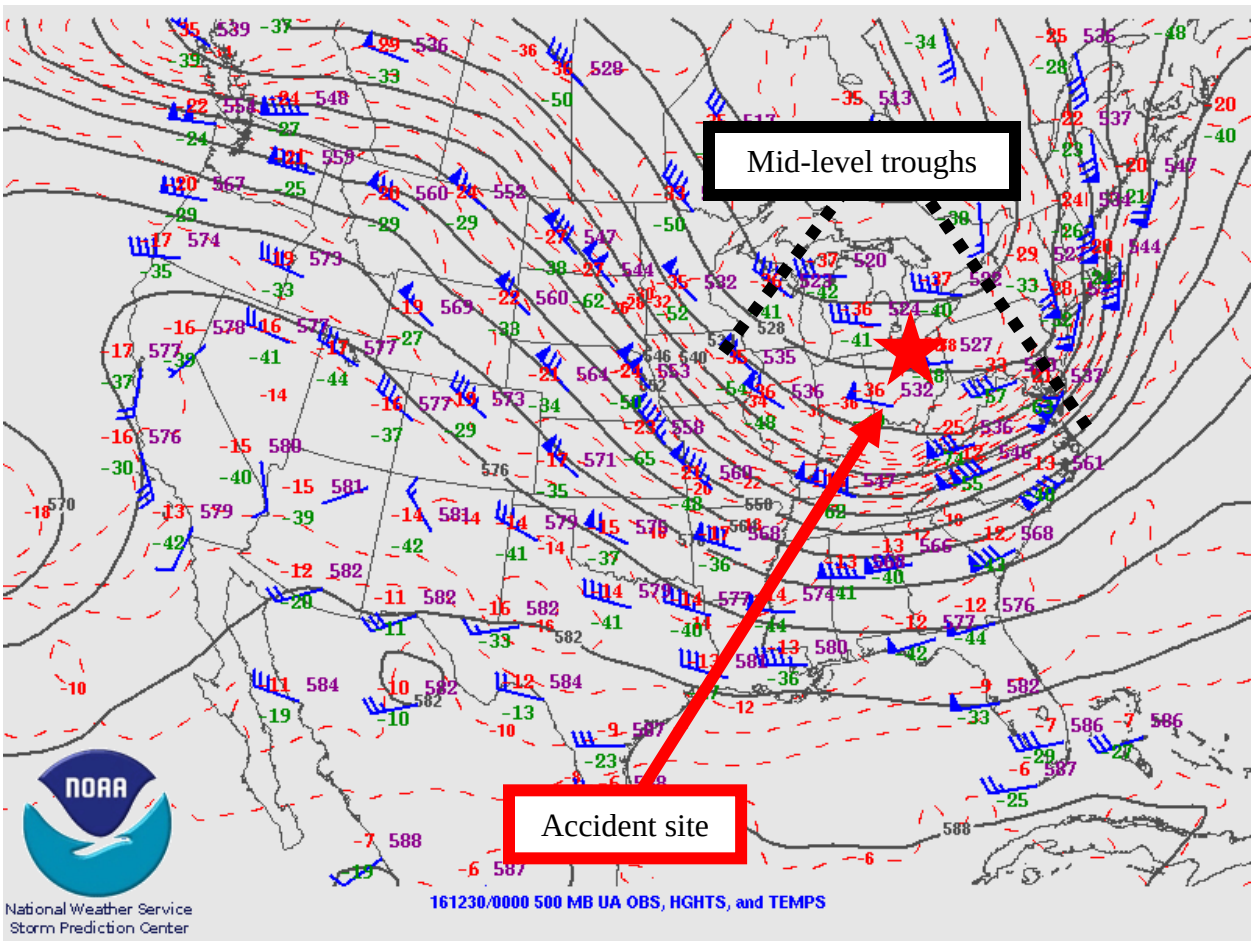

Figure 5 – 500-hPa Constant Pressure Chart for 1900 EST

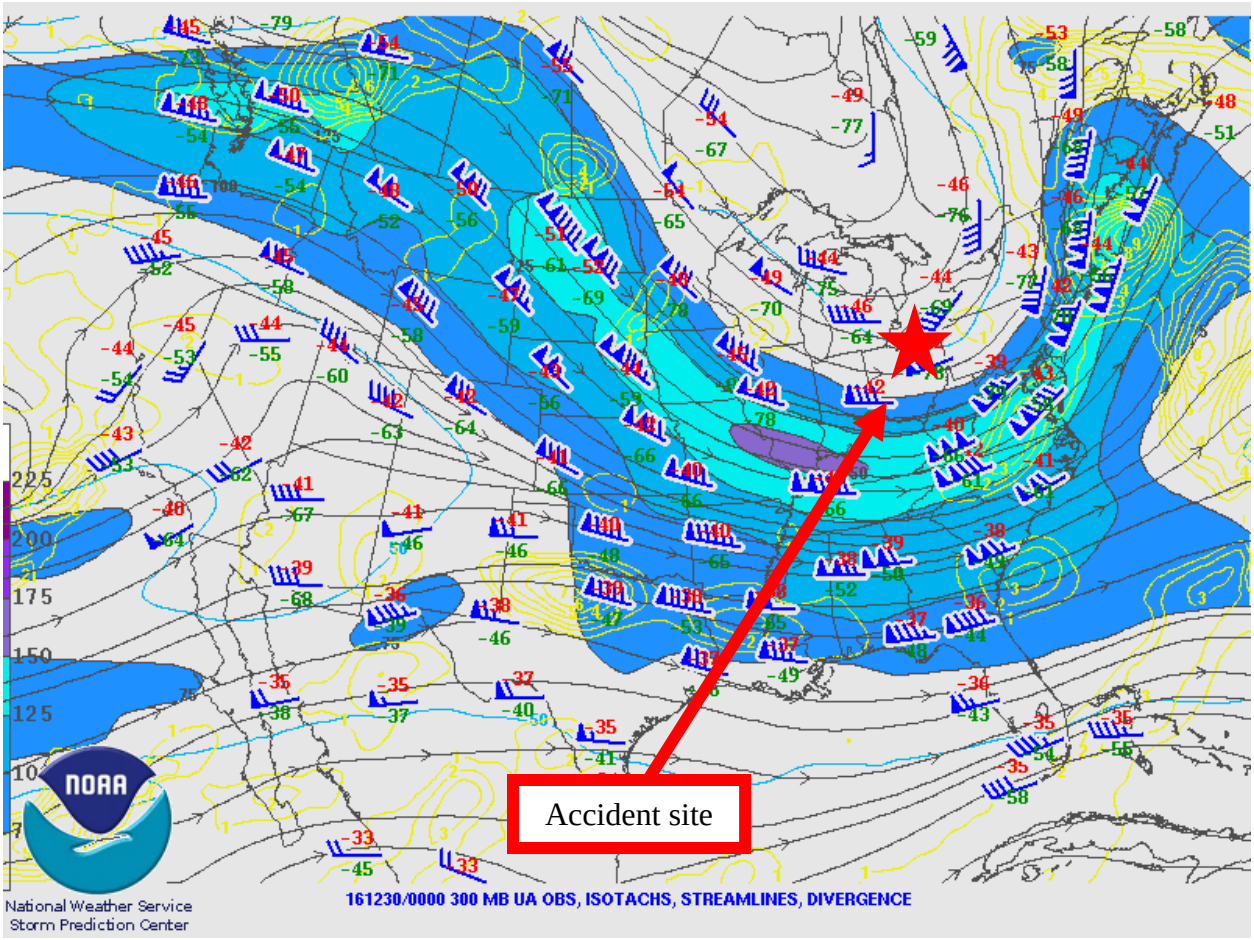

Figure 6 – 300-hPa Constant Pressure Chart for 1900 EST

2.0 SPC Products

There were no thunderstorms forecast for the accident site at the accident time.

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 with visibility reported in statute miles for this section. Figure 7 is a sectional chart with the accident site and the closest weather reporting locations marked.

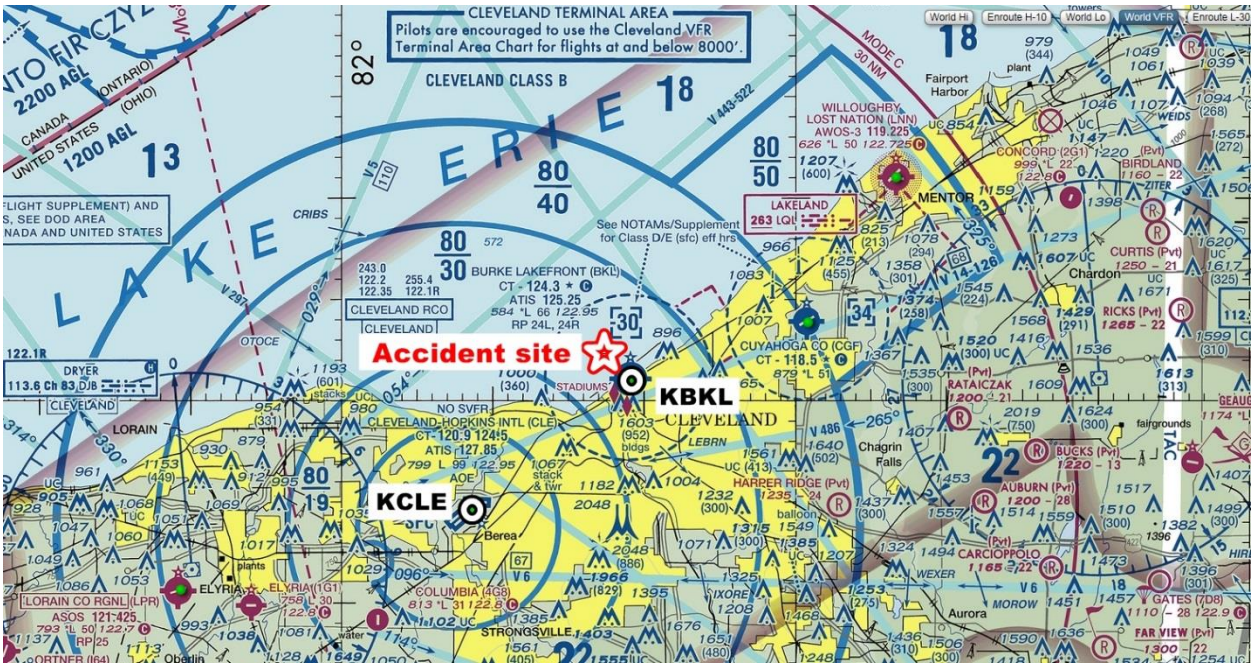

Figure 7 – Sectional chart of accident area with the location of the accident site and surface observation sites

Burke Lakefront Airport (KBKL) was the closest official weather station to the accident site, located 1 mile north of Cleveland, Ohio. KBKL had an Automated Surface Observing System (ASOS[2]) whose reports were supplemented by air traffic control. KBKL was located 2 miles southeast of the accident site, at an elevation of 584 feet, and had a 7° westerly magnetic variation[3] (figure 7). The following observations were taken and disseminated during the times surrounding the accident: [4]

[2103 EST] SPECI KBKL 300203Z 26021G27KT 8SM -SN FEW007 BKN018 OVC026 01/M01 A2972 RMK AO2 PK WND 26027/0202 P0001 T00111006=

[2128 EST] SPECI KBKL 300228Z 27020G33KT 10SM FEW016 SCT028 OVC050 01/M02 A2972 RMK AO2 PK WND 27033/0208 SNE19 P0001 T00111022=

[2151 EST] SPECI KBKL 300251Z 26025G34KT 10SM BKN021 BKN028 OVC060 01/M02 A2972 RMK AO2 PK WND 27034/0248 SNE19 P0001=

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

[3] Magnetic variation – The angle (at a particular location) between magnetic north and true north. 1990, latest measurement taken from http://www.airnav.com/airport/KBKL

[4] 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.

[2153 EST] METAR KBKL 300253Z 26026G34KT 10SM BKN021 BKN028 OVC065 01/M02 A2972 RMK AO2 PK WND 27034/0248 SNE19 SLP071 P0001 60001 T00111022 55001=

[2233 EST] SPECI KBKL 300333Z 26024G29KT 6SM -SN BR BKN012 OVC019 01/M02 A2974 RMK AO2 PK WND 26035/0254 SNB0259 P0000 T00061017=

[2245 EST] SPECI KBKL 300345Z 26023G32KT 6SM -SN BR SCT012 BKN021 OVC026 01/M02 A2973 RMK AO2 PK WND 26035/0254 SNB0259 P0000 T00061017=

[2253 EST] METAR KBKL 300353Z 26025G31KT 8SM -SN BKN013 BKN022 OVC032 01/M02 A2974 RMK AO2 PK WND 26035/0254 SNB0259 SLP076 P0000 T00061017=

ACCIDENT TIME 2258 EST

[2300 EST] SPECI KBKL 300400Z 26022G31KT 9SM SCT015 BKN023 OVC039 01/M02 A2974 RMK AO2 PK WND 26027/0356 SNE0355 P0000 T00061017=

[2353 EST] METAR KBKL 300453Z 27023G31KT 9SM -SN BKN018 OVC050 01/M02 A2974 RMK AO2 PK WND 26033/0440 SNE0355B42 SLP074 P0000 T00111022 400440006=

[0000 EST on December 30] SPECI KBKL 300500Z 27024G30KT 8SM -SN SCT016 SCT024 OVC050 01/M02 A2974 RMK AO2 PK WND 27030/0500 P0000 T00111017=

[0016 EST on December 30] SPECI KBKL 300516Z 28025G32KT 5SM -SN SCT018 BKN028 OVC050 01/M02 A2974 RMK AO2 PK WND 28032/0516 P0000 T00061022=

KBKL weather at 2245 EST, wind from 260° at 23 knots with gusts to 32 knots, 6 miles visibility, light snow, mist, scattered clouds at 1,200 feet above ground level (agl), broken ceiling at 2,100 feet agl, overcast skies at 2,600 feet agl, temperature of 1° Celsius (C), dew point temperature of -2° C, and an altimeter setting of 29.73 inches of mercury. Remarks, station with a precipitation discriminator, peak wind from 260° at 35 knots at 2154 EST, snow began at 2159 EST, one-hourly precipitation of a trace, temperature 0.6° C, dew point temperature -1.7° C.

KBKL weather at 2253 EST, wind from 260° at 25 knots with gusts to 31 knots, 8 miles visibility, light snow, broken ceiling at 1,300 feet agl, broken skies at 2,200 feet agl, overcast skies at 3,200 feet agl, temperature of 1° C, dew point temperature of -2° C, and an altimeter setting of 29.74 inches of mercury. Remarks, station with a precipitation discriminator, peak wind from 260° at 35 knots at 2154 EST, snow began at 2159 EST, sea level pressure 1007.6 hPa, one-hourly precipitation of a trace, temperature 0.6° C, dew point temperature -1.7° C.

KBKL weather at 2300 EST, wind from 260° at 22 knots with gusts to 31 knots, 9 miles visibility, scattered clouds at 1,500 feet agl, broken ceiling at 2,300 feet agl, overcast skies at 3,900 feet agl, temperature of 1° C, dew point temperature of -2° C, and an altimeter setting of 29.74 inches of mercury. Remarks, station with a precipitation discriminator, peak wind from 260° at 27 knots at 2256 EST, snow ended at 2255 EST, one-hourly precipitation of a trace, temperature 0.6° C, dew point temperature -1.7° C.

KBKL weather at 2353 EST, wind from 270° at 23 knots with gusts to 31 knots, 9 miles visibility, light snow, broken ceiling at 1,800 feet agl, overcast skies at 5,000 feet agl, temperature of 1° C, dew point temperature of -2° C, and an altimeter setting of 29.74 inches of mercury. Remarks, station with a precipitation discriminator, peak wind from 260° at 33 knots at 2340 EST, snow ended at 2255 EST and snow began again at 2342 EST, sea level pressure 1007.4 hPa, one-hourly precipitation of a trace, temperature 1.1° C, dew point temperature -2.2° C, 24-hour maximum temperature of 4.4° C, 24-hour minimum temperature of 0.6° C.

Cleveland Hopkins International Airport (KCLE) had an ASOS whose reports were supplemented by an official human observer. KCLE was located 10 miles southwest of the accident site, at an elevation of 799 feet, and had a 7° westerly magnetic variation[5] (figure 7). The following observations were taken and disseminated during the times surrounding the accident:

[2129 EST] SPECI KCLE 300229Z 27015KT 7SM -SN BKN015 BKN021 OVC026 01/M02 A2977 RMK AO2 P0000 T00061022=

[2151 EST] METAR KCLE 300251Z 28013KT 3/4SM -SN FEW008 BKN016 OVC022 01/M02 A2977 RMK AO2 SLP088 P0000 60031 T00061022 51003=

[2201 EST] SPECI KCLE 300301Z 27014KT 2SM -SN BR SCT011 OVC018 00/M02 A2977 RMK AO2 P0001 T00001022=

[2207 EST] SPECI KCLE 300307Z 26013KT 3SM -SN BR FEW008 SCT011 OVC018 00/M02 A2977 RMK AO2 P0001 T00001022=

[2226 EST] SPECI KCLE 300326Z 26016KT 1SM -SN BKN014 OVC022 00/M03 A2977 RMK AO2 P0001 T00001028=

[2236 EST] SPECI KCLE 300336Z 27015KT 3SM -SN OVC014 00/M03 A2978 RMK AO2 P0001 T00001028=

[2251 EST] METAR KCLE 300351Z 26013KT 5SM -SN OVC014 00/M03 A2978 RMK AO2 SLP090 P0001 T00001028=

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[5] Magnetic variation – The angle (at a particular location) between magnetic north and true north. 1990, latest measurement taken from http://www.airnav.com/airport/KCLE

[2309 EST] SPECI KCLE 300409Z 26013KT 9SM -SN SCT014 BKN018 OVC023 01/M03 A2978 RMK AO2 P0000 T00061028=

[2351 EST] METAR KCLE 300451Z 27016G21KT 3SM -SN BKN017 BKN024 OVC055 00/M03 A2978 RMK AO2 SLP091 P0001 T00001028 400560000=

[0051 EST on December 30] METAR KCLE 300551Z 28015G22KT 9SM -SN SCT016 BKN028 OVC065 00/M03 A2978 RMK AO2 PK WND 29029/0518 SLP091 P0000 60032 4/002 T00001033 10033 20000 51004=

[0112 EST on December 30] SPECI KCLE 300612Z 27012KT 10SM SCT018 SCT026 OVC065 00/M03 A2978 RMK AO2 SNE0558 P0000 T00001033=

KCLE weather at 2236 EST, wind from 270° at 15 knots, 3 miles visibility, light snow, overcast ceiling at 1,400 feet agl, temperature of 0° C, dew point temperature of -3° C, and an altimeter setting of 29.78 inches of mercury. Remarks, station with a precipitation discriminator, one-hourly precipitation of 0.01 inches, temperature 0.0° C, dew point temperature -2.8° C.

KCLE weather at 2251 EST, wind from 260° at 13 knots, 5 miles visibility, light snow, overcast ceiling at 1,400 feet agl, temperature of 0° C, dew point temperature of -3° C, and an altimeter setting of 29.78 inches of mercury. Remarks, station with a precipitation discriminator, sea-level pressure of 1009.0 hPa, one-hourly precipitation of 0.01 inches, temperature 0.0° C, dew point temperature -2.8° C.

KCLE weather at 2309 EST, wind from 260° at 13 knots, 9 miles visibility, light snow, scattered clouds at 1,400 feet agl, broken ceiling at 1,800 feet agl, overcast skies at 2,300 feet agl, temperature of 1° C, dew point temperature of -3° C, and an altimeter setting of 29.78 inches of mercury. Remarks, station with a precipitation discriminator, one-hourly precipitation of a trace, temperature 0.6° C, dew point temperature -2.8° C.

KCLE weather at 2351 EST, wind from 270° at 16 knots with gusts to 21 knots, 3 miles visibility, light snow, broken ceiling at 1,700 feet agl, broken skies at 2,400 feet agl, overcast skies at 5,500 feet agl, temperature of 0° C, dew point temperature of -3° C, and an altimeter setting of 29.78 inches of mercury. Remarks, station with a precipitation discriminator, sea-level pressure 1009.1 hPa, one-hourly precipitation of 0.01 inches, temperature 0.0° C, dew point temperature -2.8° C, 24-hour maximum temperature of 5.6° C, 24-hour minimum temperature of 0.0° C.

3.1 One Minute Wind Observations

The one-minute KBKL ASOS surface data was provided by the NWS for the time surrounding the accident. One-minute raw wind data was provided with two separate magnitudes and wind directions[6]. The first wind data in table 1 is the two-minute average wind speed, which was updated every 5 seconds and reported once a minute. The second source of one-minute wind data is the five-second maximum wind average, which was updated every five seconds and reported once every minute (table 1). The one-minute weather observation, temperature (in °F), and dew point temperature (in °F) are also included in table 1. The following table provides the meteorological data in local time (EST) as well as UTC time.

[6] The wind directions are in reference to true north.

Time (EST)	Time UTC	Dir of 2min avg wind	Speed of 2min avg wind (knots)	Dir of max 5 sec avg wind	Speed of max 5 sec avg wind (knots)	Weather	TEMP °F	DEWPT °F
2241	0341	259	23	263	32	S-	33	29
2242	0342	259	23	258	24	S-	33	29
2243	0343	257	21	260	26	S-	33	29
2244	0344	256	23	256	27	S-	33	29
2245	0345	255	23	257	26	S-	33	29
2246	0346	255	22	253	26	S-	33	29
2247	0347	255	22	250	28	?2	33	29
2248	0348	256	22	262	25	?1	33	29
2249	0349	256	22	256	27	?1	33	29
2250	0350	256	21	253	25	?1	33	29
2251	0351	255	22	250	29	?1	33	29
2252	0352	257	25	264	29	NP	33	29
2253	0353	259	25	256	31	NP	33	29
2254	0354	258	22	250	25	NP	33	29
2255	0355	256	22	267	27	NP	34	29
2256	0356	256	23	258	27	NP	33	29
2257	0357	256	22	258	24	NP	33	29
2258	0358	256	21	261	27	NP	34	29
2259	0359	256	21	255	25	NP	33	29
2300	0400	255	22	256	26	NP	33	29
2301	0401	256	23	259	27	NP	33	29
2302	0402	256	22	256	26	NP	33	29
2303	0403	256	21	261	23	NP	34	29
2304	0404	258	20	258	23	NP	34	29
2305	0405	258	20	262	27	NP	34	29
2306	0406	261	22	261	29	NP	34	29
2307	0407	264	23	267	26	NP	34	29
2308	0408	264	21	261	23	NP	34	29
2309	0409	262	21	257	25	NP	34	29
2310	0410	263	22	264	26	NP	34	29
2311	0411	264	21	270	24	NP	34	29
2312	0412	264	21	265	29	NP	34	30
2313	0413	265	22	274	28	NP	34	29

Table 1 – One-minute KBKL ASOS data for the time surrounding the accident

At 2257 EST, KBKL reported the two-minute average wind from 256° at 22 knots, a five-second maximum average wind from 258° at 24 knots, no significant weather, temperature of 33° F, and dew point temperature of 29° F.

At 2258 EST, KBKL reported the two-minute average wind from 256° at 21 knots, a five-second maximum average wind from 261° at 27 knots, no significant weather, temperature of 34° F, and dew point temperature of 29° F.

At 2259 EST, KBKL reported the two-minute average wind from 256° at 21 knots, a five-second maximum average wind from 255° at 25 knots, no significant weather, temperature of 33° F, and dew point temperature of 29° F.

The observations from KBKL and KCLE surrounding the accident time indicated MVFR[7] conditions around the accident site with IFR[8] conditions due to low visibility in snow at KCLE 30 minutes before the accident time. Precipitation was reported in the one-minute observations at KBKL until 2251 EST, with no precipitation reported at the surface at KBKL until 2342 EST. While the surface temperature remained above freezing around the accident time and after the accident plane landed at KBKL, the dew point temperature remained below freezing the entire time with precipitation occurring on and off in the snow shower activity. The movement and areal coverage of precipitation with the accident flight track will be further discussed in section 6.4.

4.0 Upper Air Data

A High-Resolution Rapid Refresh (HRRR)[9] model sounding was created for the accident site for 2300 EST. The 2300 EST sounding was plotted on a standard Skew-T log P diagram[10] with the derived stability parameters included in figure 8 (with data from the surface to 700-hPa, or 10,000 feet msl.) This data was analyzed utilizing the RAOB[11] software package. The sounding depicted the lifted condensation level (LCL)[12] at 1,773 feet msl, a convective condensation level (CCL)[13] of 2,744 feet, and a level of free convection (LFC)[14] at 1,814 feet. The freezing level was at 963 feet. The precipitable water value was 0.29 inches.

[7] 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 inclusive and/or 3 to 5 miles visibility.
[8] 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.
[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, Matamopras, Pennsylvania.
[12] Lifting Condensation Level (LCL) - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.
[13] 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.
[14] 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.

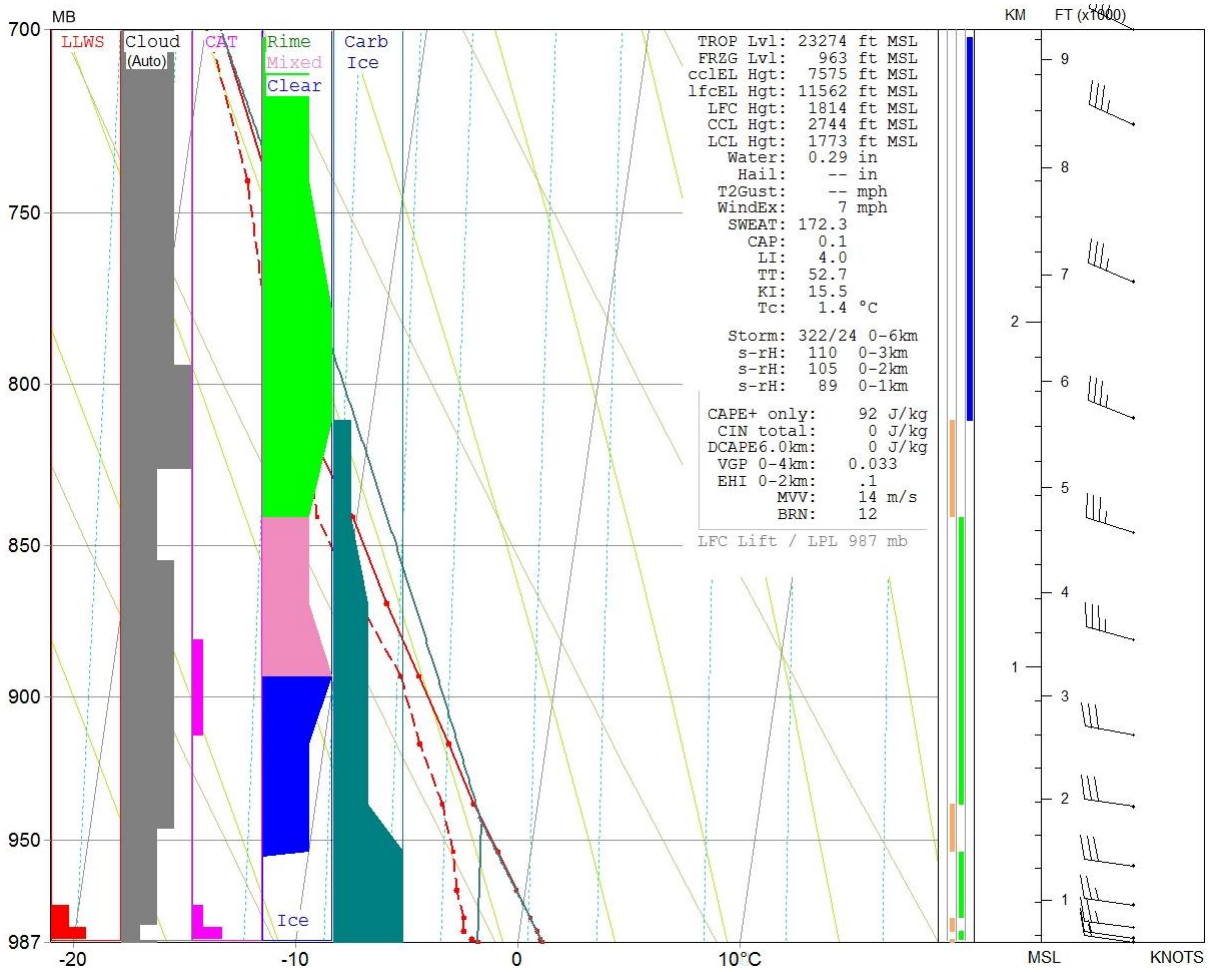


Figure 8 – 2300 EST HRRR sounding for the accident site

The 2300 EST HRRR sounding indicated an unstable to conditionally unstable layer between the surface and 5,750 feet. A stable layer was present from 5,750 feet through 10,000 feet. RAOB indicated that clouds were likely from the surface through 10,000 feet. Moderate or greater clear, mixed, and rime icing conditions were indicated by RAOB between the surface and 10,000 feet. There was sufficient moisture in the favored dendritic growth zone between -10° C and -20° C, and therefore precipitation would be expected at the surface within the snow shower activity. With sufficient moisture in the dendritic growth zone, supercooled liquid water would have likely been present in the cloud cover between the surface and 10,000 feet.[15] Icing potential will be further discussed in section 15.0. Section 17.0 will further discuss lake effect snow and its environment.

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

The 2300 EST HRRR sounding wind profile indicated a surface wind from 278° at 17 knots with the wind remaining westerly through 10,000 feet. The wind increased in speed to 30 knots by 1,400 feet and remained between 30 to 35 knots through 10,000 feet. RAOB indicated the possibility of light to moderate low-level wind shear between the surface and 1,000 feet, with light to moderate clear-air turbulence possible between the surface and 4,000 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 Man-computer Interactive Data Access System software. Visible and infrared imagery (GOES-13 bands 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 1700 EST through 0200 EST (on December 30) at approximately 15-minute intervals were reviewed, and the closest images to the time of the accident are documented here.

Figures 9 and 10 present the GOES-13 infrared imagery from 2245 and 2300 EST at 7X magnification with the accident site highlighted with a red square. Inspection of the infrared imagery indicated abundant clouds over the accident site at the accident time with the cloud cover moving from west to east (attachment 1). The lower brightness temperatures (green colors, higher cloud tops) were over Lake Huron and in eastern Ohio around the accident time. Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 2300 EST HRRR sounding, the approximate cloud-top heights over the accident site were estimated at 10,500 feet at 2300 EST (figure 10). It should be noted these figures have not been corrected for any parallax error. Based on the surface observations (section 3.0), the 2300 EST HRRR sounding data (section 4.0), and the infrared satellite imagery, the accident flight likely encountered instrument meteorological conditions above 1,800 feet msl shortly after takeoff with icing conditions (section 6.4).

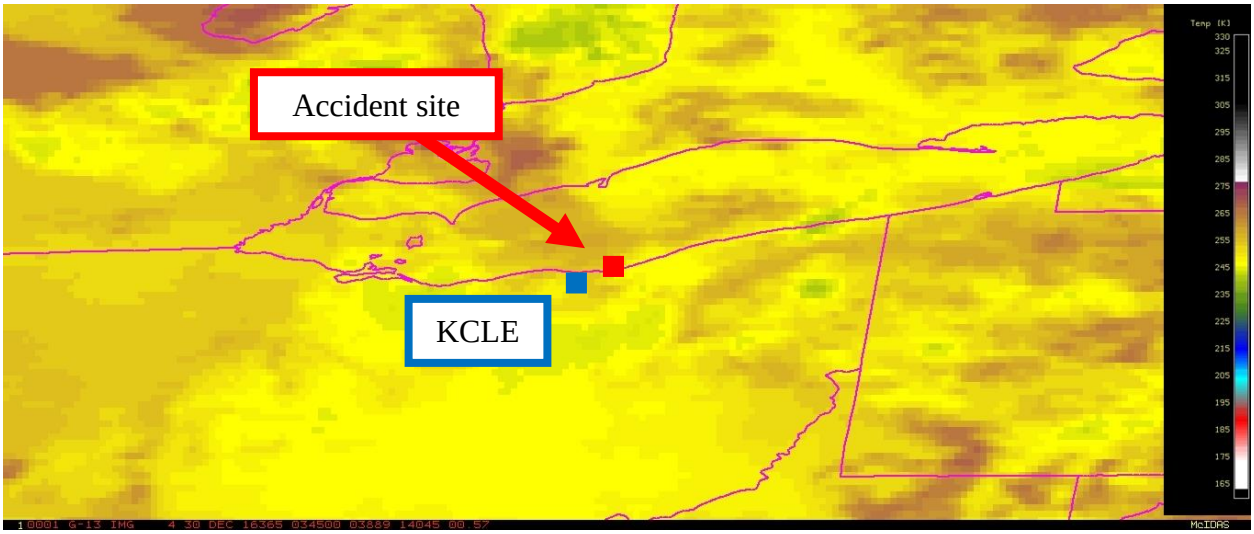


Figure 9 – GOES-13 infrared image at 2245 EST

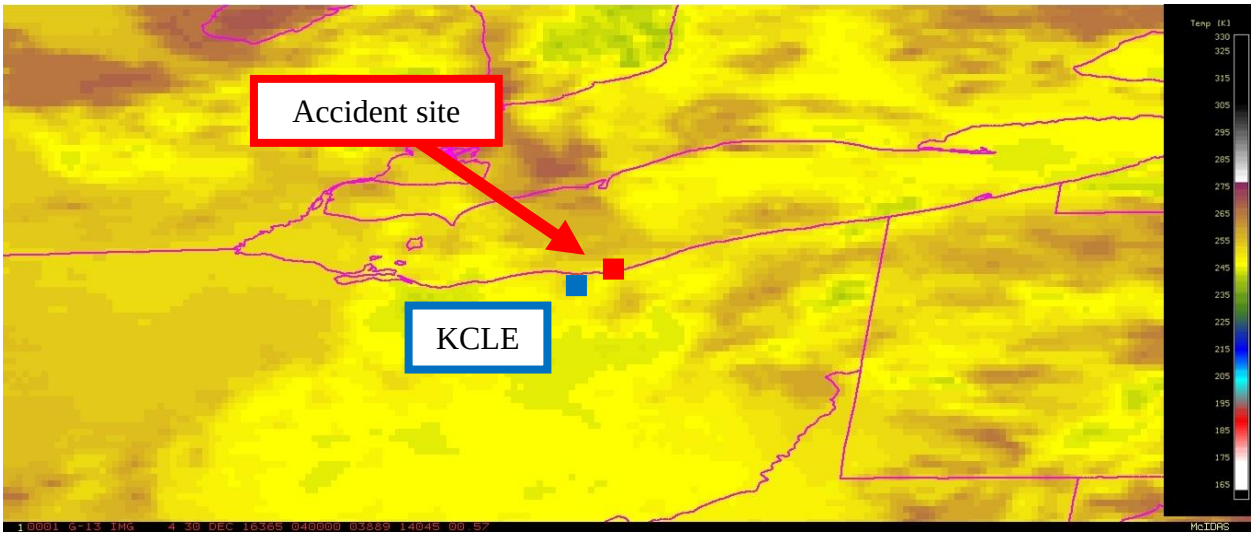


Figure 10 – GOES-13 infrared image at 2300 EST

6.0 Radar Imagery Information

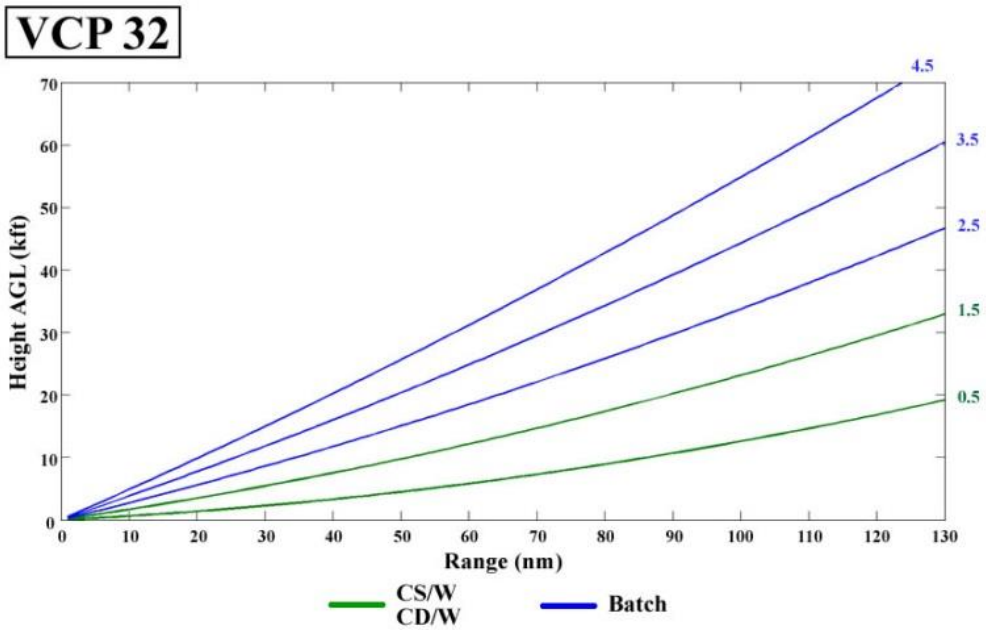
The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)[16] to the accident site was the Cleveland, Ohio, radar (KCLE), which was located 8 miles southwest of the accident site at an elevation of 763 feet. Level II and III archive radar data were obtained from the NCEI utilizing the NEXRAD 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 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 KCLE WSR-88D radar was operating in the clear-air mode (Mode B, VCP-32). 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.

[16] 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-32 Clear-Air Mode Scan Strategy[17]

6.2 Beam Height Calculation

Assuming standard refraction[18] of the WSR-88D 0.95° wide radar beam, the following table shows the approximate beam height and width[19] information[20] of the radar display over the site of the accident. The heights have been rounded to the nearest 10 feet.

ANTENNA ELEVATION	BEAM CENTER	BEAM BASE	BEAM TOP	BEAM WIDTH
0.5°	1,230 feet	840 feet	1,620 feet	780 feet
1.5°	2,070 feet	1,680 feet	2,460 feet	780 feet

[17] Contiguous Surveillance (CS)--The low Pulse Repetition Frequency (PRF) scan of the split cut. Gives a high R_{max} value to determine proper target location and intensity, but a low V_{max} value limits the velocities that can be measured. Contiguous Doppler (CD)--The high PRF scan of the split cut. Gives a low R_{max} value causing more range folded (multiple trip) echoes, but a high V_{max} value to get higher, more accurate velocity values.
Batch Mode – Uses alternating low and high PRFs on each radial for one full rotation at each elevation angle. The two resulting data sets (low PRF and high PRF) are combined to resolve range ambiguity. Used in the middle elevation angles.
W – With range unfolding (W)
WO – Without range unfolding (WO)

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

[19] Beam width – A measure of the angular width of a radar beam.

[20] Beamwidth values are shown for legacy resolution products. Super resolution products would an effective beamwidth that would be approximately half these values.

Based on the radar height calculations, the 0.5° and 1.5° elevation scans depicted the conditions between 840 feet and 2,460 feet msl over the accident site and these scans are the closest altitudes to the accident site before the accident occurred.[21]

6.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors[22] it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in decibels (dBZ[23]), 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:

- 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.

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

[22] 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.

[23] 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.

6.4 Base Reflectivity and Lightning Data

Figures 11 and 12 present the KCLE WSR-88D base reflectivity images for the 0.5° and 1.5° elevation scans initiated at 2256 and 2258 EST, respectively, with a resolution of 0.5° X 250 m. The flight track has also been added in pink. Base reflectivity values between -10 to 5 dBZ were located above the accident site around the accident time. The precipitation bands were moving from west-northwest to east-southeast above the accident site around the accident time (attachment 2). The light snow band moved southeast of KBKL by 2246 EST (attachment 2) with only very light dBZ values indicated along the flight track around the accident. Given the very light reflectivity values, the majority of the precipitation particles likely remained in the cloud cover and with below freezing temperatures (section 4.0), and favored icing conditions. Icing potential will be further discussed in section 15.0. There were no lightning strikes around the accident site at the accident time.[24] A review of the dual-polarization level II and III data was done, but results were inconclusive.

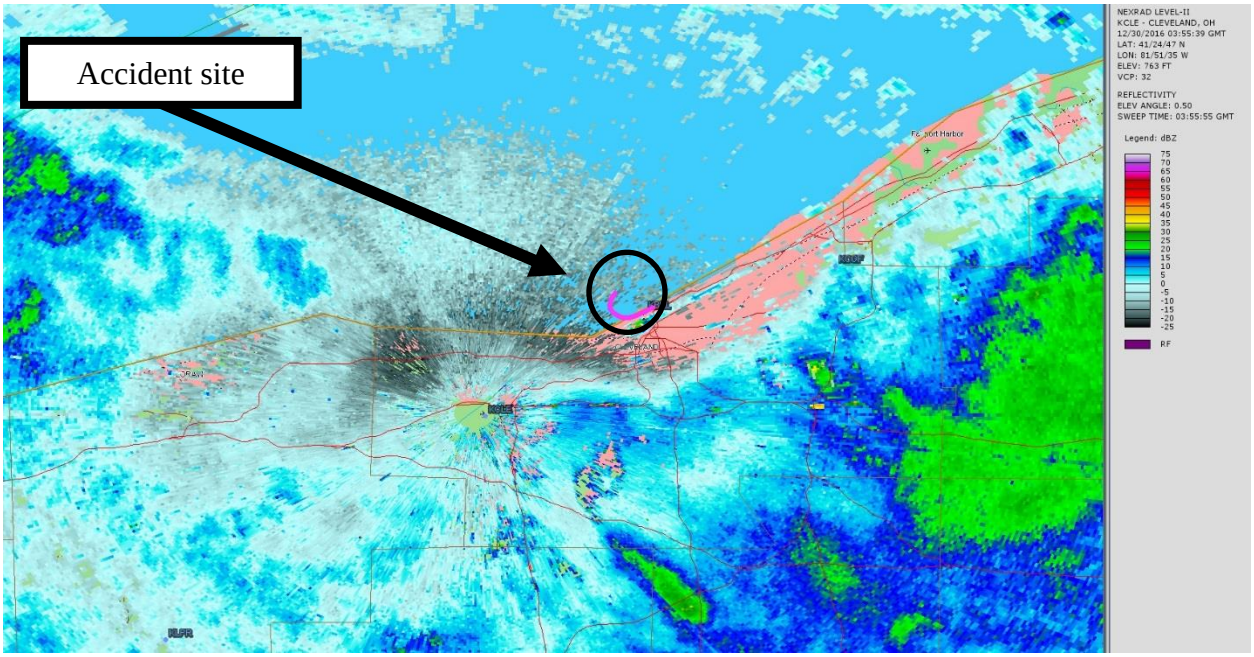


Figure 11 – KCLE WSR-88D reflectivity for the 0.5° elevation scan initiated at 2256 EST with the accident site marked with black circle and ATC track as pink dots

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

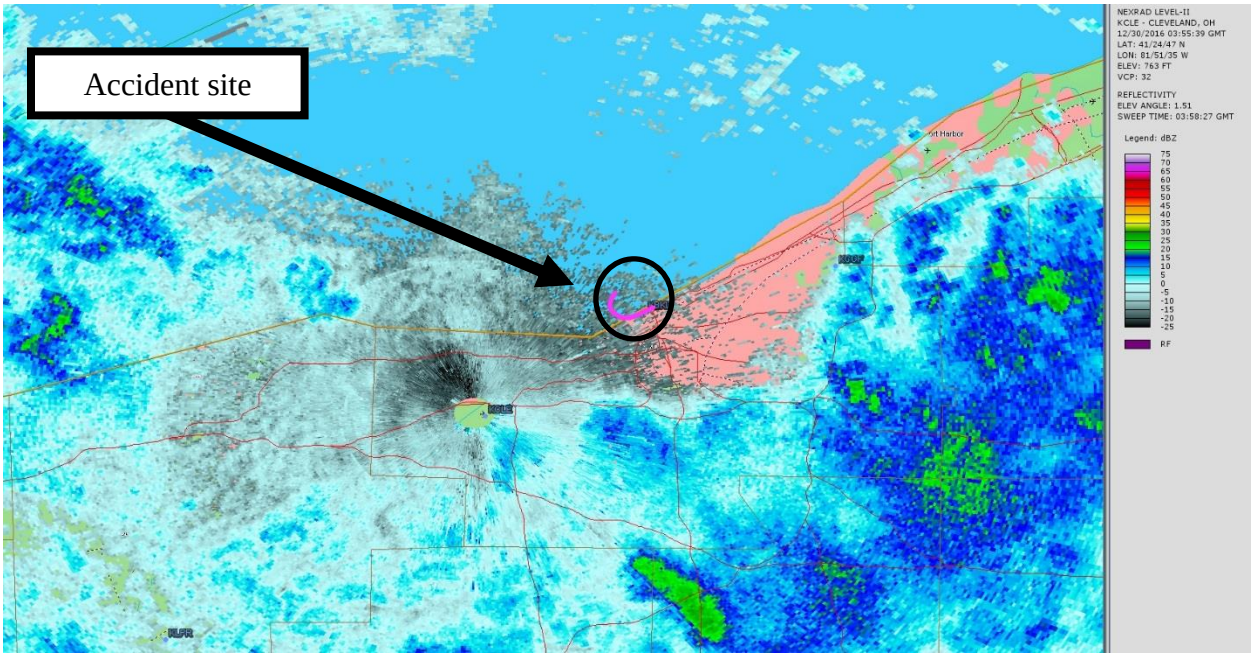


Figure 12 – KCLE WSR-88D reflectivity for the 1.5° elevation scan initiated at 2258 EST with the accident site marked with black circle and ATC track as pink dots

7.0 Pilot Reports[25]

All pilot reports (PIREPs) close to the accident site from three hours prior to the accident time to three hours after the accident time were reviewed. Only PIREPs below FL200[26] are provided below:

DTW UA /OV DXO090010/TM 0119/FL040/TP B737/TA -10 / 050/IC LT RIME AOB 170-050

DTW UA /OV DXO360020/TM 0127/FL060/TP B717/TA -12 / 070/IC LGT RIME 090-070

KDTW UA /OV KDTW/TM 0140/FL050/TP CRJ9/TA M10/IC MOD MX

CMH UA /OV CMH28005/TM 0152/FL040/TP E145/SK B038/IC NEG

YNG UUA /OV YNG240007/TM 0207/FL030/TP BK17/TA M01/IC SEV RIME

CMH UA /OV CMH090010/TM 0230/FL030/TP E175/TB MOD

CAK UA /OV CAK180010/TM 0255/FL050/TP CRJ7/TA M09/IC MOD RIME

CAK UA /OV CAK050010/TM 0408/FL030/TP A320/SK BKN030/TA M03 / 045/WV 270030 / 030/IC LIGHT TIME IC/RM BASES 030 TOPS 080

CAK UA /OV CAK/TM 0430/FLSFC/TP CRJ2/RM BRAG RWY 23

[25] Only pilot reports with the WMO header UBOH** identifier were considered.
[26] 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.

CMH UA /OV CMH135025/TM 0441/FLDURGD/TP E170/TA -12 AT 060/IC LT RIME 070-055 LT RIME 050-040

CMH UA /OV CMH090010/TM 0503/FLDURGD/TP B737/SK BKN060-TOP130/TA M27 AT 110/IC LGT RIME 130

Routine pilot report (UA); 10 miles from Detroit, Michigan, on the 090° radial; Time – 2019 EST (0119Z); Altitude – 4,000 feet; Type aircraft – Boeing B737; Temperature – -10° C; Icing – Light rime at or below 17,000 to 5,000 feet.

Routine pilot report (UA); 20 miles from Detroit, Michigan, on the 360° radial; Time – 2027 EST (0127Z); Altitude – 6,000 feet; Type aircraft – Boeing B717; Temperature – -12° C at 7,000 feet; Icing – Light rime between 9,000 and 7,000 feet.

Routine pilot report (UA); Over Detroit, Michigan; Time – 2040 EST (0140Z); Altitude – 5,000 feet; Type aircraft – Bombardier CRJ900; Temperature – -10° C; Icing – Moderate mixed.

Routine pilot report (UA); 5 miles from Columbus, Ohio, on the 280° radial; Time – 2052 EST (0152Z); Altitude – 4,000 feet; Type aircraft – Embraer ERJ145; Sky – Broken ceiling at 3,800 feet; Icing – Negative.

Urgent pilot report (UUA); 7 miles from Youngstown, Ohio, on the 240° radial; Time – 2107 EST (0207Z); Altitude – 3,000 feet; Type aircraft – MBB/Kawasaki BK 117; Temperature – -1° C; Icing – Severe rime.

Routine pilot report (UA); 10 miles from Columbus, Ohio, on the 090° radial; Time – 2130 EST (0230Z); Altitude – 3,000 feet; Type aircraft – Embraer ERJ175; Turbulence – Moderate.

Routine pilot report (UA); 10 miles from Akron, Ohio, on the 180° radial; Time – 2155 EST (0255Z); Altitude – 5,000 feet; Type aircraft – Bombardier CRJ700; Temperature – -9° C; Icing – Moderate rime.

Routine pilot report (UA); 10 miles from Akron, Ohio, on the 050° radial; Time – 2308 EST (0408Z); Altitude – 3,000 feet; Type aircraft – Airbus A320; Sky – Broken ceiling at 3,000 feet; Temperature – -3° C at 4,500 feet; Wind – From 270° at 30 knots; Icing – Light “rime” through, it was misspelled as “time” and distributed into the national airspace; Remarks – Bases at 3,000 feet with tops at 8,000 feet.

Routine pilot report (UA); Over Akron, Ohio; Time – 2330 EST (0430Z); Altitude – Surface; Type aircraft – Bombardier CRJ200; Remarks – Braking action good on runway 23.

Routine pilot report (UA); 25 miles from Columbus, Ohio, on the 135° radial; Time – 2341 EST (0441Z); Altitude – During descent; Type aircraft – Embraer ERJ170; Temperature – -12° C at 6,000 feet; Icing – Light rime between 7,000 and 5,500 feet, light rime between 5,000 and 4,000 feet.

Routine pilot report (UA); 10 miles from Columbus, Ohio, on the 090° radial; Time – 0003 EST on December 30 (0503Z); Altitude – During descent; Type aircraft – Boeing B737; Sky – Broken ceiling at 6,000 feet with tops 13,000 feet; Temperature – -27° C at 11,000 feet; Icing – Light rime at 13,000 feet.

8.0 SIGMET and CWSU Advisory

There were no Significant Meteorological Information advisories valid for the accident site at the accident time. No Center Weather Service Unit (CWSU) Center Weather Advisories (CWA)s were valid for the accident site at the accident time.

The Cleveland Air Route Traffic Control Center CWSU issued Meteorological Impact Statements (MIS) number 3, and the MIS was valid for the accident site at the accident time. The MIS was issued at 2040 EST and discussed ceilings below 5,000 feet with light to patchy moderate icing between 1,500 and 8,000 feet. Patchy IFR conditions were expected with light snow showers and blowing snow, with patchy moderate turbulence below 5,000 feet, and local surface wind gusts to 30 to 35 knots. No weather forecast updates would be made after 2130 EST as the CWSU was closed after 2130 EST:

FAUS20 KZOB 300140
ZOB MIS 03 VALID 300141-301300
...FOR ATC PLANNING PURPOSES ONLY...
THRUT..CIG BLW 050. LGT-PTCHY MOD ICE 015-080. NE OH/PA/NY.. PTCHY IFR -SHSN/BLSN. PTCHY MOD TURB BLW 050. LOCAL SFC GUST 30-35KT. EXTRM NE OH/NW PA/W NY..AREAS IFR SHSN/BLSN. ISOL 1 TO 2 INCH/HR SNOWFALL. W 1/3 ZOB..ISOL IFR. NO UPDT AFT 0230Z.
=

9.0 AIRMETs

Airmen's Meteorological Information (AIRMET) advisories Zulu, Tango, and Sierra were issued at 2145 EST and valid at the accident time for the accident site (figures 13 and 14). The AIRMETs forecasted IFR conditions due to precipitation and mist, moderate icing conditions below 10,000 feet, and moderate turbulence below 10,000:

345
WAUS41 KKCI 300245
WA1Z
-BOSZ WA 300245
AIRMET ZULU FOR ICE AND FRZLVL VALID UNTIL 300900
.
...SEE SIGMET UNIFORM SERIES...
.
AIRMET ICE...ME NH VT MA RI CT NY AND CSTL WTRS
FROM 70NW PQI TO 60NE PQI TO 140E ACK TO 90SE ACK TO 50SE HTO TO 60WSW YSC TO YSC TO 70NW PQI
MOD ICE BTN FRZLVL AND FL180. FRZLVL SFC-090. CONDS CONTG BYD 09Z ENDG 12-15Z.
.
AIRMET ICE...NH VT MA CT NY LO NJ PA OH LE WV MD VA
FROM 60WSW YSC TO 50SW CON TO 30ENE EMI TO 40SW HAR TO 30E PSK TO

HMV TO HNN TO CVG TO FWA TO DXO TO MSS TO 60WSW YSC
MOD ICE BLW 100. CONDS CONTG BYD 09Z THRU 15Z.
.
OTLK VALID 0900-1500Z...ICE ME NH VT MA NY LO PA OH LE WV MD VA
BOUNDED BY 70NW PQI-60NE PQI-30SSE HUL-CON-20WNW SAX-40SW HAR-30E
PSK-40N HMV-HNN-CVG-FWA-DXO-MSS-YSC-70NW PQI
MOD ICE BLW 100. CONDS CONTG THRU 15Z.
.
FRZLVL...RANGING FROM SFC-035 ACRS AREA
SFC ALG 40SSW PSK-20WNW CSN-20SSW CON-20SW MLT-40ESE HUL
....

998
WAUS41 KKCI 300245
WA1T
-BOST WA 300245
AIRMET TANGO FOR TURB STG WNDS AND LLWS VALID UNTIL 300900
.
AIRMET TURB...ME NH VT MA RI CT NY NJ PA MD DC DE VA AND CSTL
WTRS
FROM 70NW PQI TO 60NE PQI TO 200SE ACK TO 160SE SIE TO 20NE ECG
TO HMV TO 20SSW DCA TO 20SSE ETX TO MSS TO YSC TO 70NW PQI
MOD TURB BLW FL180. CONDS CONTG BYD 09Z THRU 15Z.
.
AIRMET TURB...NY LO PA OH LE WV MD DC VA
FROM MSS TO 20SSE ETX TO 30SSW DCA TO HMV TO HNN TO CVG TO FWA
TO DXO TO MSS
MOD TURB BLW 100. CONDS CONTG BYD 09Z THRU 15Z.
.
AIRMET TURB...ME NH VT MA RI CT NY LO NJ PA OH WV MD DC DE VA
AND CSTL WTRS
FROM 70NW PQI TO 60NE PQI TO 200SE ACK TO 160SE SIE TO 20NE ECG
TO HMV TO HNN TO CVG TO 40SSE FWA TO 20SSW AIR TO 40SE JST TO
20N ETX TO 40N SYR TO MSS TO YSC TO 70NW PQI
MOD TURB BTN FL180 AND FL390. CONDS CONTG BYD 09Z THRU 15Z.
.
AIRMET STG SFC WNDS...ME NH MA RI CT NY NJ MD DE VA CSTL WTRS
FROM 60SW YSJ TO 200SE ACK TO 180SE SIE TO 120E ORF TO 60SSE JFK
TO 40S PVD TO ACK TO 30ENE ENE TO 60SW YSJ
SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG BYD 09Z
THRU 15Z.
.
LLWS POTENTIAL...ME AND CSTL WTRS
BOUNDED BY 70NW PQI-60NE PQI-150ESE ACK-60E ENE-40E YSC-70NW PQI
LLWS EXP. CONDS CONTG BYD 09Z ENDG 09-12Z.
.
OTLK VALID 0900-1500Z
AREA 1...TURB ME NH VT MA RI CT NY LO NJ PA OH LE WV MD DC DE VA
AND CSTL WTRS
BOUNDED BY YSC-70S BGR-50SSE PVD-30E JFK-20NE ECG-HMV-HNN-CVG-
FWA-20NE DXO-MSS-YSC
MOD TURB BLW 100. CONDS CONTG THRU 15Z.
.
AREA 2...TURB OH LE WV
BOUNDED BY DXO-30SSW AIR-HNN-CVG-FWA-DXO
MOD TURB BTN FL200 AND FL370. CONDS DVLPG 12-15Z. CONDS CONTG

THRU 15Z.
....

601
WAUS41 KKCI 300245
WA1S
-BOSS WA 300245
AIRMET SIERRA FOR IFR AND MTN OBSCN VALID UNTIL 300900
.
AIRMET IFR...ME NH VT MA RI CT NY LO PA AND CSTL WTRS
FROM 70NW PQI TO 60NE PQI TO 200SE ACK TO 170SSE ACK TO 50SSE
ACK TO 30S BOS TO 20S BDL TO 30S HNK TO 70SSW SYR TO 30WNW SYR
TO 70SSW YOW TO MSS TO YSC TO 70NW PQI
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG BYD 09Z THRU 15Z.
.
AIRMET IFR...NY LO PA OH LE WV MD VA
FROM 40NNE BUF TO 50SW SYR TO 50E EKN TO 20ENE PSK TO HMV TO
40NNE HNN TO 20SW APE TO 50S DXO TO 20SW BUF TO 40NNE BUF
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG BYD 09Z THRU 15Z.
.
AIRMET MTN OBSCN...ME NH VT MA NY PA WV MD VA
FROM 70NW PQI TO MLT TO CON TO HAR TO 30NW CSN TO 40S PSK TO HMV
TO HNN TO JHW TO SYR TO MSS TO YSC TO 70NW PQI
MTNS OBSC BY CLDS/PCPN/BR. CONDS CONTG BYD 09Z THRU 15Z.
....

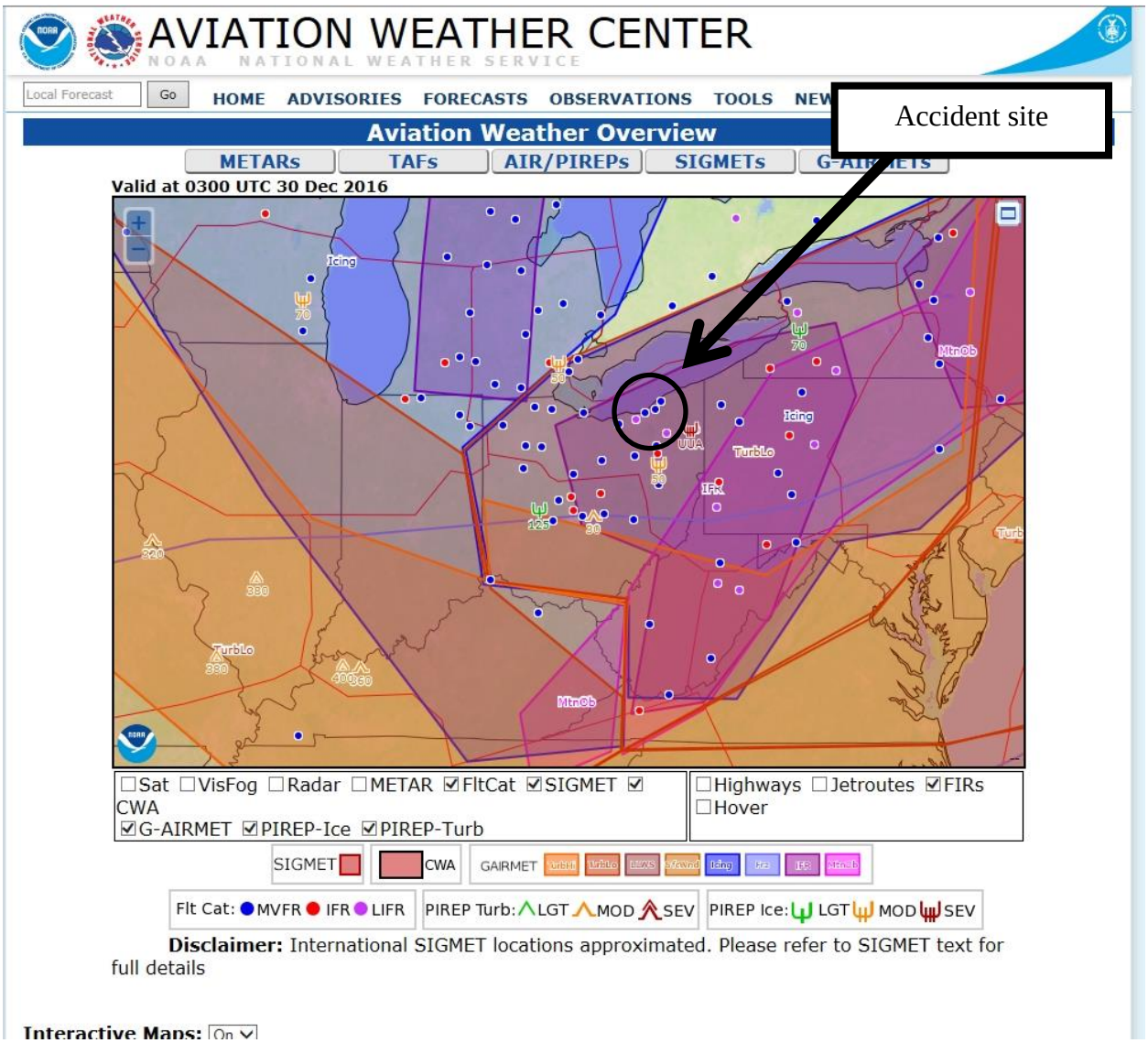


Figure 13 –AIRMETs valid for the accident area for 2200 EST

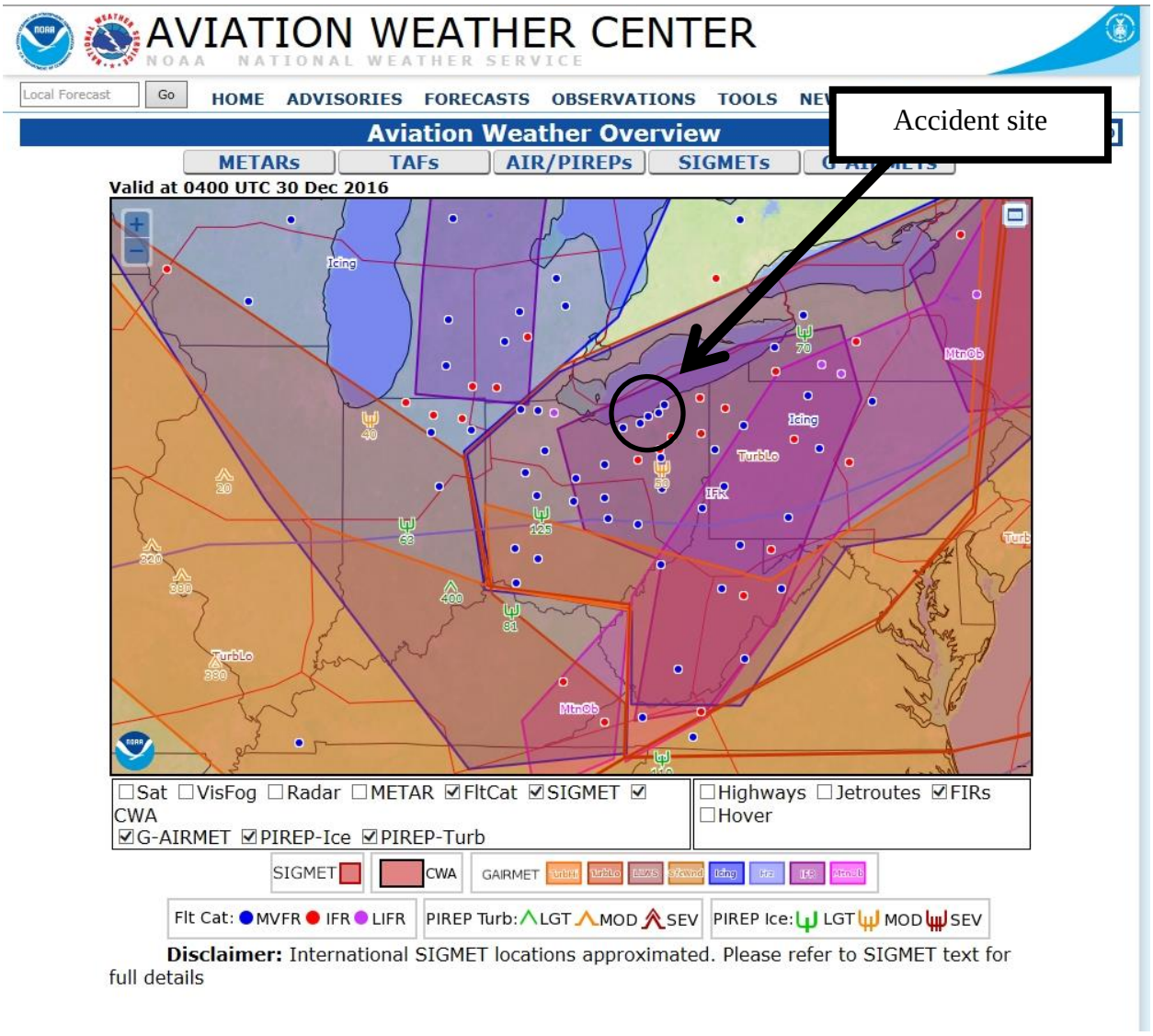


Figure 14 –AIRMETs valid for the accident area for 2300 EST

10.0 Area Forecast

The Area Forecast issued at 2045 EST, and valid at the accident time, forecasted an overcast ceiling at 2,500 feet with tops at 12,000 feet, visibilities between 3 to 5 miles in scattered light snow showers, and a west wind with gusts to 25 knots:

689
FAUS41 KKCI 300145
FA1W
-BOSC FA 300145
SYNOPSIS AND VFR CLDS/WX
SYNOPSIS VALID UNTIL 302000
CLDS/WX VALID UNTIL 301400...OTLK VALID 301400-302000
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...LOW PRES OVR SERN MA WITH CDFNT SWD THRU ATLC WTRS. BY 12Z LOW OVR NERN ME AND MOVG N OF FA BY 15Z. TROF OVR S CNTRL PA-CNTRL MD-S CNTRL VA WL MOV LTL THRU 20Z.
.
ME
CSTL SXNS...OVC010 LYRD FL250. VIS 3SM -RA/BR. WND SE 25G35KT. BECMG 0709 OVC020 TOP FL180. VIS 3-5SM -RA/BR. WND W 20G30KT THRUT. 12Z BKN040. OTLK...VFR WND.
RMNDR...OVC010-020 LYRD FL250. VIS 3SM -SN/BLSN. WND SE 20G30KT. 09Z TOP FL180. 12Z N PTN OVC015-025. VIS 3SM -SN/BLSN. WND W G25KT. S PTN BKN030 TOP 120. WDLY SCT -SHSN. WND W 20G30KT. OTLK...N PTN MVFR CIG SHSN WND S PTN VFR WND TIL 18Z SHSN.
.
NH VT
SERN NH...OVC010-015 TOP FL200. VIS 3SM -SN/BLSN. WND NW 20G30KT. BECMG 0709 BKN040 TOP 100. WND W G25KT. OTLK...VFR WND.
RMNDR NH/VT...OVC020-030 TOP FL220. VIS 3-5SM -SN/BLSN. 06Z WND W 20G30KT. 09Z TOP 120. OTLK...MVFR CIG SHSN WND.
.
MA RI CT
WRN-CNTRL MA/CT...BKN025 BKN040 TOP 160. N PTN WDLY SCT -SHSN. WND W 20G30KT THRUT. 08Z SCT-BKN040 TOP 120. OTLK...XTRM W MA MVFR CIG SHSN WND ELSW VFR WND.
ERN MA/RI...OVC015 TOP FL200. VIS 3-5SM -RASN. WND NW 25G40KT THRUT. BECMG 0608 SCT025 SCT040. OTLK...VFR WND.
.
NY LO
NERN-N CNTRL NY...OVC015-025 TOP 140. VIS 3-5SM -SN. 06Z TOP 120. OTLK...MVFR CIG SHSN WND.
SERN NY-LONG ISLAND...
CSTL PLAIN..BKN-SCT070 TOP 100. WND NW 20G30KT. 08Z SCT040. WND W G25KT. OTLK...VFR WND.
RMNDR SERN NY..BKN020-030 TOP 120. WDLY SCT -SHSN. WND NW G25KT. OTLK...MVFR CIG SHSN WND.
S CNTRL-WRN NY/LO...BKN-OVC030 TOP 120-140. OCNL VIS 3SM SCT -SHSN. WND NW G25KT. OTLK...SWRN NY IFR CIG SHSN WND ELSW MVFR CIG SHSN WND.
.
PA NJ
NJ/SERN PA...SCT040. WND W G25KT. 12Z SRN NJ SCT040 SCT080. OTLK...VFR WND.
NERN-CNTRL PA...BKN035 TOP 100-120. WDLY SCT -SHSN. WND NW G25KT. OTLK...S PTN VFR WND N PTN MVFR CIG SHSN WND.
WRN PA...OVC020-030 TOP 120-140. VIS 3-5SM SCT -SHSN. WND NW G25KT. OTLK...IFR CIG SHSN WND.
.
OH LE
OVC025 TOP 120. VIS 3-5SM SCT -SHSN. WND W G25KT. OTLK...MVFR CIG SHSN WND 18Z S PTN VFR WND.
.
WV MD DC DE VA
W OF APLCNS...BKN040 TOP 100. 04Z OVC030 TOP 120. VIS 3-5SM SCT -SHSN. OTLK...MVFR CIG SHSN WND.

APLCNS...OVC030-050 TOP 120-140. OCNL VIS 3-5SM SCT -SHSN. WND NW G25KT. OTLK...MVFR CIG SHSN WND.
PIEDMONT...SCT050. OTLK...VFR WND.
CSTL PLAIN...SCT050. XTRM N WND NW G25KT. 10Z E PTN SCT050 SCT100. OTLK...VFR WND.
.
CSTL WTRS
ACK NWD...OVC010-020 TOP FL220. VIS 3-5SM -RA/BR. WND SE 30G45KT. BECMG 0608 BKN010-020 TOP 080. XTRM NRN VIS 3SM -RA/BR. WND W 30G40KT THRUT. 12Z BKN025. OTLK...N PTN MVFR CIG WND S PTN VFR WND.
RMNDR...
PVD EWD..OVC010 TOP 080. VIS 3SM -RA/BR. WND W 30G45KT. BECMG 0507 BKN030. WND NW 30G40KT. OTLK...OFFSHORE MVFR CIG WND ELSW VFR WND.
W OF PVD...BKN-SCT100 TOP 140. WND NW 30G40KT. 08Z SCT030 SCT100. WND W 25G35KT. OTLK...VFR WND.
....

11.0 Terminal Aerodrome Forecast

KCLE was the closest site to the accident site with a NWS Terminal Aerodrome Forecast (TAF). The TAF valid at the time of the accident was issued at 2041 EST and was valid for a 28-hour period beginning at 2100 EST. The TAF for KCLE was as follows:

KCLE 300141Z 3002/3106 **26015G25KT P6SM OVC025**
TEMPO 3002/3004 3/4SM -SN OVC006
FM300400 27015G25KT 5SM -SHSN OVC025
FM301000 27015G25KT 2SM -SHSN OVC025
FM301400 28015G25KT 5SM -SHSN OVC025
FM301900 27015G25KT P6SM OVC035
FM302200 26012KT P6SM OVC035
FM310000 24006KT P6SM SCT035=

The forecast expected a wind from 260° at 15 knots with gusts to 25 knots, greater than 6 miles visibility, and an overcast ceiling at 2,500 feet agl. Temporary conditions were forecast between 2100 and 2300 EST of three quarters of a mile visibility, light snow, and an overcast ceiling at 600 feet agl.

12.0 NWS Area Forecast Discussion

The NWS Office in Cleveland, Ohio, issued the following Area Forecast Discussion (AFD) at 2121 EST (closest AFD to the accident time with an aviation section). The aviation section of the AFD discussed lake effect snow gradually developing across the area with MVFR conditions expected:

536
FXUS61 KCLE 300221
AFDCLE

Area Forecast Discussion
National Weather Service Cleveland OH

921 PM EST Thu Dec 29 2016

.SYNOPSIS...
Low pressure which will remain northeast of the Great Lakes through Friday will take a trough across the area tonight. High pressure will move across the Gulf Coast states Friday bringing a ridge to the Ohio Valley. A clipper will track east-southeast across the lakes Saturday. High pressure will have another brief stay here Sunday.

&&

.NEAR TERM /UNTIL 6 AM FRIDAY MORNING/...
The first in a series of upper waves has crossed I-71 and is heading toward the PA border. Cloud tops are warming and the snow intensity has diminished from an hour or two ago. There was actually some lightning in Cuyahoga County as the band moved through. Looking at water vapor imagery some drying is noted behind the wave. A second wave is currently crossing the western Lakes and will arrive later tonight. Expect the synoptic snow to continue to diminish the next few hours and then pick up again later tonight as the next wave arrives. We should also see the lake become more involved as slightly colder air arrives aloft. Have gone ahead and lowered precip chances and amounts in the west. Bumped up accums slightly in the southeast end of the area where the band of snow is currently heading. No changes to the lake effect snow headlines. Have had a few reports of 3 or 4 inches already today.

&&

.SHORT TERM /6 AM FRIDAY MORNING THROUGH SUNDAY NIGHT/...
Lake effect snow showers will persist through the day Friday across the snow belt. Parameters remain favorable into the afternoon hours with lake-850mb differentials peaking at 15C and lake induced inversion heights remaining in the 10-12kft range. Snow will slowly diminish after 21Z Friday as drier air moves into the area and surface ridge axis moves east across the area. Lingering snow showers are possible for a few hours after Midnight in NW PA, but much of the snow across NE OH will end between 00Z-06Z. Storm total snowfall amounts in NW PA of 6 to 8 inches expected and possible amounts up to 12 inches in eastern Erie and northern Crawford. General amounts of 6 to 8 inches expected in northern Geauga, with 3 to 6 inches expected in the advisory areas. Also cut back the end time of the advisories/warnings in NE OH to 03Z.

Saturday will begin dry across the area with surface high pressure centered southeast of the area. A low will track through the northern Great Lakes with a trailing cold front approaching the area Saturday night. Models continue to indicate precip overspreading the area ahead of the front Saturday afternoon/evening. Holding with chance pops as of now for this time period. Soundings indicate mainly snow Saturday afternoon/night with some rain possibly mixing in Saturday afternoon. Accumulations should be minimal with surface temperatures remaining near/above freezing into early evening, and most of the precip ending by then.

Another shortwave will lift northeast from the southern Plains toward the Great Lakes Sunday. Precip expected to overspread the area from southwest to northeast late Sunday afternoon/Sunday evening. There may be a mix of rain/snow at the onset but given pretty strong WAA with this system, expecting mainly rain, especially after 06Z. No major changes to temps from previous forecast for the Friday through Sunday night period.

&&

.LONG TERM /MONDAY THROUGH THURSDAY/...
Arctic air will return to the region during this period. Mild conditions are expected on Monday as low pressure tracks by to the north and west and places the region in the warm sector with 850 mb temperatures warming to near 8-10C as the upper level ridge shifts east off the east coast. The pattern gradually changes as the upper level trough gradually shifts east into the upper Mississippi Valley and the trailing cold front moves into the region late Tuesday or Tuesday night with some disagreement between the ECMWF and GFS. The GFS is faster with the progression of the front as it has a stronger shortwave lifting ne through the region on Tuesday.

Temperatures will begin falling Tuesday night and continue to drop into Thursday. Near the end of the period...the models diverge. The ECMWF produces an inverted trough northward in the Ohio Valley which could spread precipitation back into the region. For now will trend with the GFS and linger lake effect snows primarily in the snowbelt as arctic air spreads eastward.

&&

.AVIATION /00Z Friday THROUGH Tuesday/...
Lake effect snow will gradually develop across the area as colder air moves east southeast into the forecast area. Ceilings just west of the forecast area are around 1500 feet at this time advancing east. Otherwise, skies just east of this area remain VFR. Visibilities will be reduced to MVFR through the night into tomorrow, especially where the snow showers persist. High pressure ridge will begin to build in tomorrow and we should see the snow gradually begin to end in the afternoon.

OUTLOOK...VFR into Saturday then non-VFR returning later Saturday and continuing much of the time through Tuesday.

&&

.MARINE...
Low pressure over eastern Ontario extended a cold front over the area this morning. As the low moves off to the east, eventually becoming absorbed in a stronger low over the New England states, a strong pressure gradient should set up over the Great Lakes allowing for winds to 30 knots and waves to build above 4 feet across the basin with waves to 8 feet possible in the eastern zones. Thus, a small craft advisory is in place through Friday night/Saturday morning. A ridge of high pressure will build in

behind the low on Friday into Saturday but a new low will quickly come digging in from the west not allowing for the pressure gradient to relax. Thus, winds should still be in the 25 to 30 knots range but from the south. With low-level winds forecasted to be about 50 knots, could certainly get close to gales if the air mixes down, but plenty of uncertainty remains, so left the forecast below gales for now. Once this clipper low moves east of the area Saturday night into Sunday morning, winds should relax and become fairly light as high pressure moves in for the start of next week.

&&

.CLE WATCHES/WARNINGS/ADVISORIES...
OH...Lake Effect Snow Advisory until 10 PM EST Friday for OHZ012-
014-023-089.
Lake Effect Snow Warning until 10 PM EST Friday for OHZ013.
PA...Lake Effect Snow Advisory until 4 AM EST Saturday for PAZ001.
Lake Effect Snow Warning until 4 AM EST Saturday for PAZ002-
003.
MARINE...Small Craft Advisory until 1 AM EST Saturday for LEZ146>149.
Small Craft Advisory until 7 PM EST Friday for LEZ142>145.

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$$

13.0 Winds and Temperature Aloft Forecast

The NWS 2056 EST Winds and Temperature Aloft forecast valid for the accident flight are included below:

```
259
FBUS31 KWNO 300156
FD1US1
-DATA BASED ON 300000Z
VALID 300600Z   FOR USE 0200-0900Z. TEMPS NEG ABV 24000

FT  3000    6000    9000   12000   18000   24000  30000  34000  39000
-CLE 2937 3035-14 3032-19 2935-26 2939-36 3049-46 295345 295244 285743
```

The accident site was closest to the Cleveland (CLE), Ohio, forecast point. The 2056 EST CLE forecast indicated a wind at 3,000 feet from 290° at 37 knots and a wind at 6,000 feet from 300° at 35 knots with a temperature of -14° C.

14.0 Pilot Weather Briefing

A search of official weather briefing sources, such as Lockheed Martin Flight Service (LMFS) and Direct User Access Terminal Service (DUATS) was done and the accident pilot did receive an official text weather briefing from LMFS before the flight from Ohio State University Airport (KOSU) to KBKL at 1449 EST. In addition, the accident pilot requested and received an official text weather briefing from LMFS at 0947 EST. The accident pilot did not receive an updated briefing before departing from KBKL back to KOSU. The 1449 LMFS text weather briefing contained all the standard weather briefing information including the latest METARs for departure, destination, and enroute, AIRMETs, Area Forecast, PIREPs (none were available), SPC Convective Outlook, and Winds Aloft Forecast (attachment 3). A search of ForeFlight weather information revealed that the accident pilot did request a weather briefing using ForeFlight Mobile prior to his flight from KOSU to KBKL, but did not request a weather briefing before the accident flight from KBKL to KOSU (attachment 4). The weather briefing provided by ForeFlight Mobile prior to the flight from KOSU to KBKL contained the same information as the LMFS text information above, except the ForeFlight Mobile weather information was in a graphical format with the flight track from KOSU to KBKL plotted for pilot reference (attachment 4).

There were no additional weather briefings requested by the accident pilot via either ForeFlight Mobile or LMFS. The accident pilot did recheck his proposed flight performance information at 2230:16 EST (attachment 5) for the accident flight from KBKL back to KOSU. The accident pilot did not look at any weather imagery (e.g., Prog Charts, G-AIRMETs, Icing information, etc…) before or during the accident flight using ForeFlight, LMFS, or DUATS, however, the accident pilot could have reviewed weather graphics from additional internet sources. The accident pilot could have accessed other "live" text weather information such as METARs/TAFs, etc… (attachment 5) on ForeFlight, but because that information is not logged by ForeFlight it is not known if the pilot accessed other "live" text weather information. One of the accident pilot's devices did access the airport page for KBKL at 2213:55 EST, where he could have viewed KBKL weather, but that information is not logged (attachment 5). One of the accident pilot's devices did access the airport page for KOSU at 2230:11 EST, where he could have viewed KOSU weather, but that information is not logged (attachment 5).It is unknown if the accident pilot checked or received any more weather information before or during the accident flight.

15.0 Icing Potential[27]

Current Icing Potential (CIP) and Forecast Icing Potential (FIP) products are created by the NWS' Aviation Weather Center (AWC) and are intended to be supplemental to other icing advisories (e.g. AIRMETs and SIGMETs). Figures 15 through 17 were the FIP icing probabilities and icing severity products, 2-hour forecast valid at 2300 EST at 1,500, 2,000, 2,500 feet msl (similar values in the FIP are seen in the 1-hour forecast valid at both 2200 and 2300 EST, attachment 6). The FIP indicated between a 20 to 50 percent probability of icing at 1,500, 2,000, and 2,500 feet at 2300 EST at the accident site. The FIP also indicated that the icing near the accident site would likely be light (figures 15, 16, and 17). The FIP did not indicate any Supercooled Large Droplet (SLD) potential over the accident area around the accident time (attachment 6). This FIP information would have been available on the NWS AWC website well before the accident flight departed KBKL.[28]

The CIP product indicated between a 30 to 70 percent probability of icing at 1,500, 2,000, and 2,500 feet at 2300 EST at the accident site. The CIP also indicated that the icing near the accident site would likely be trace to light intensity (figures 18, 19, and 20). The CIP also did not indicate a chance of SLD near the accident site around the accident time. While the probability of icing was not high, the FIP and CIP products did indicate icing conditions were still favorable over the area (figures 15 through 20 and attachment 6). For more FIP and CIP information and altitudes please see attachment 6.

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

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

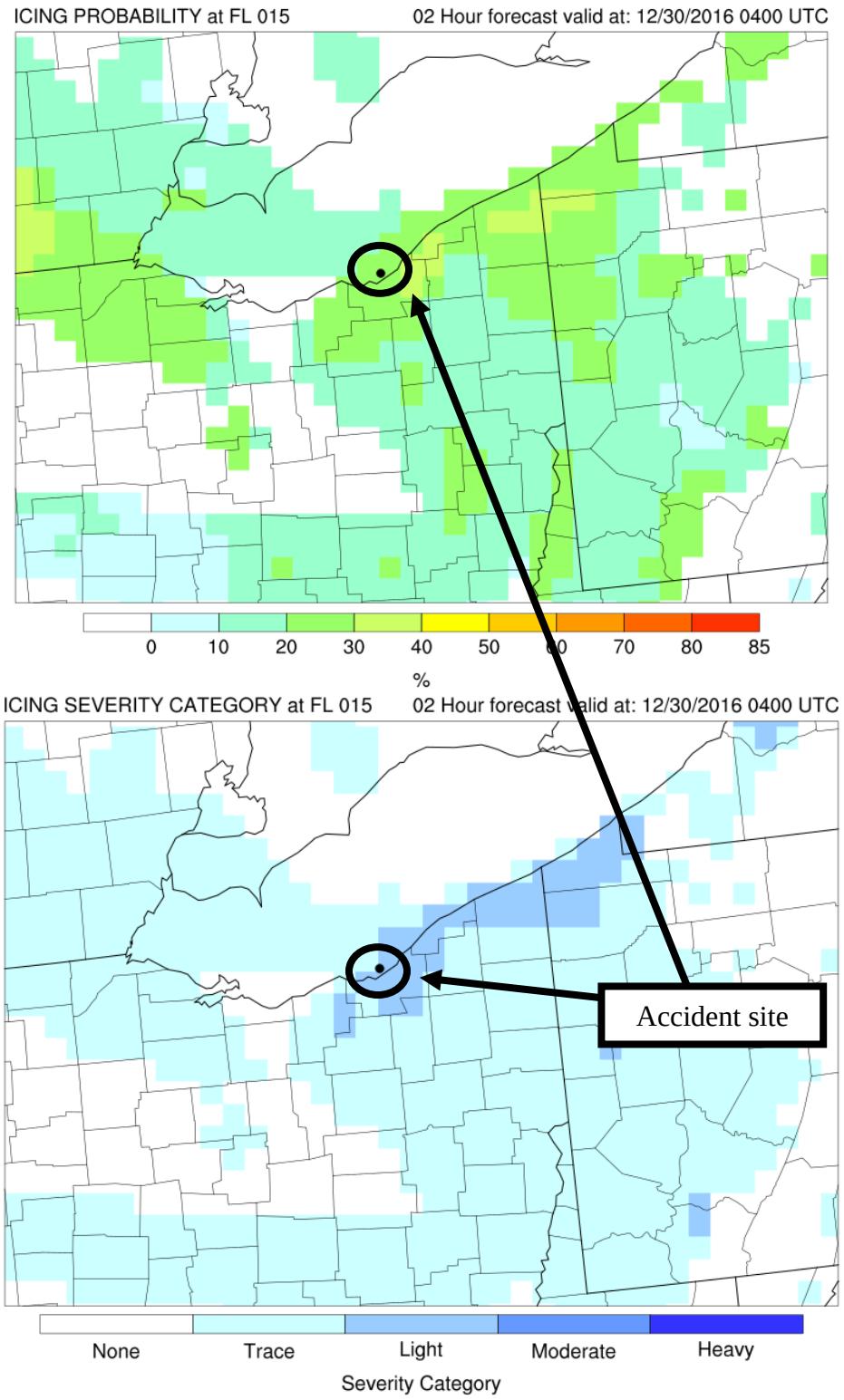

Figure 15 – (top) FIP probability of icing at 1,500 feet msl and (bottom) FIP severity of icing at 1,500 feet msl 2-hour forecast valid for 2300 EST

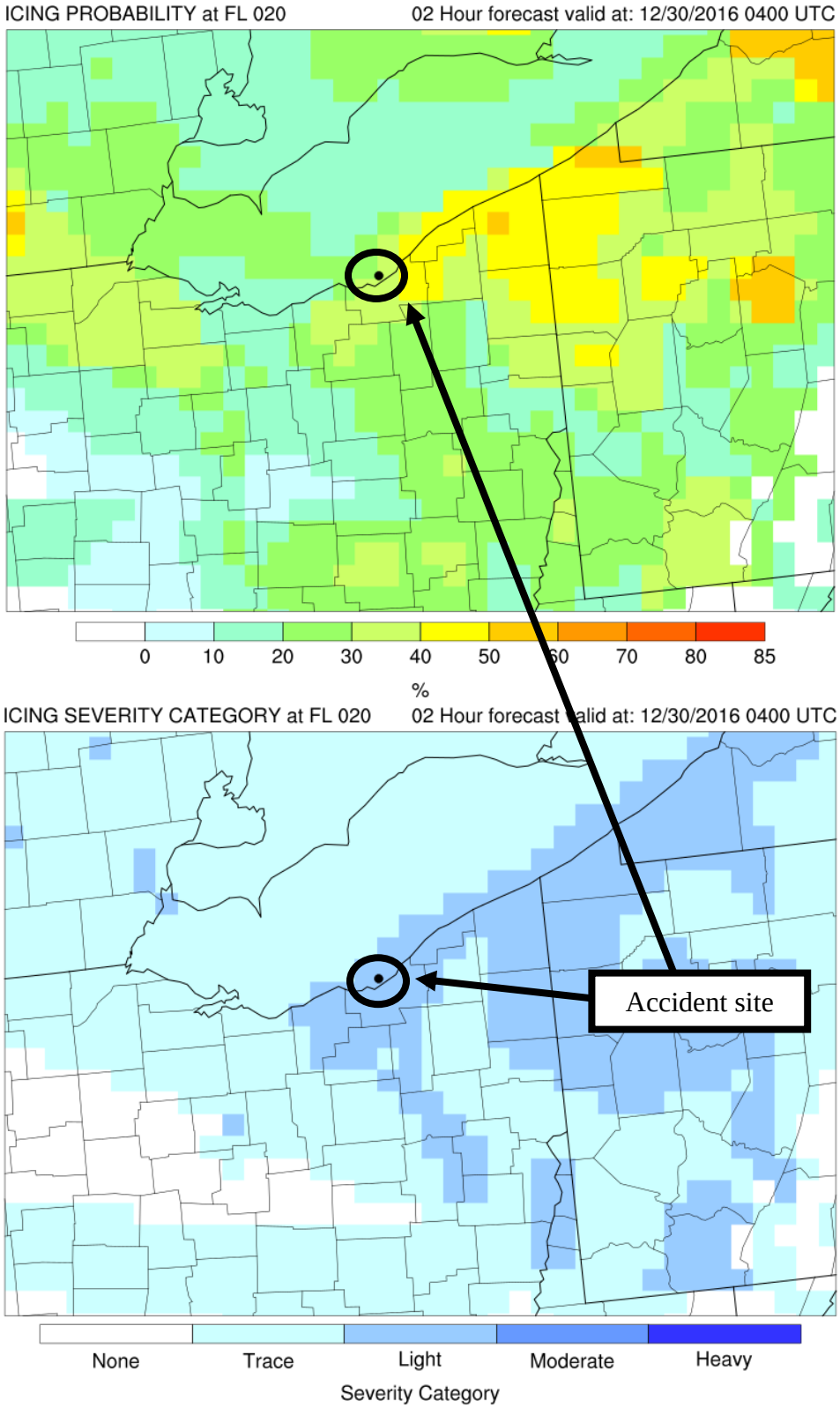

Figure 16 – (top) FIP probability of icing at 2,000 feet msl and (bottom) FIP severity of icing at 2,000 feet msl 2-hour forecast valid for 2300 EST

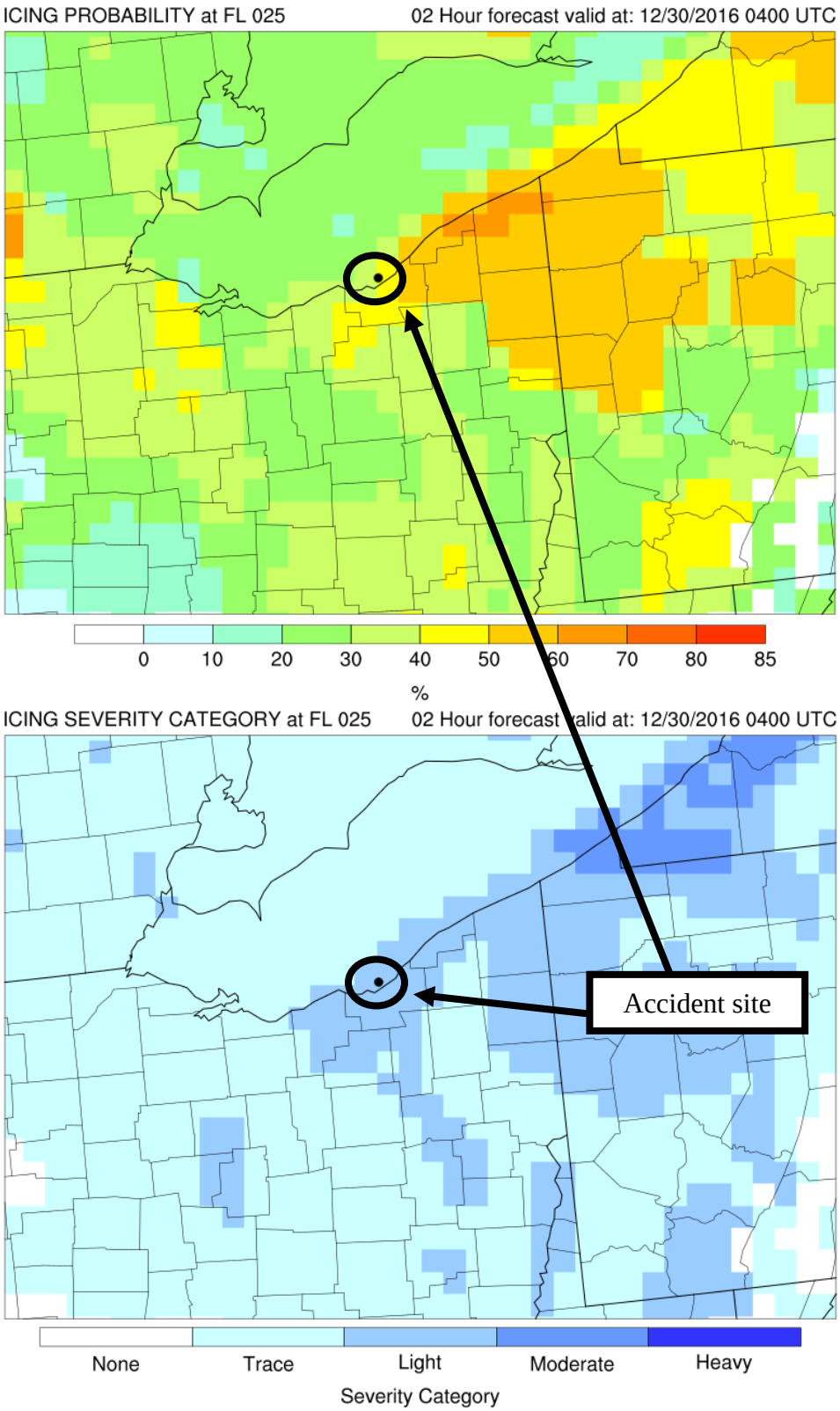

Figure 17 – (top) FIP probability of icing at 2,500 feet msl and (bottom) FIP severity of icing at 2,500 feet msl 2-hour forecast valid for 2300 EST

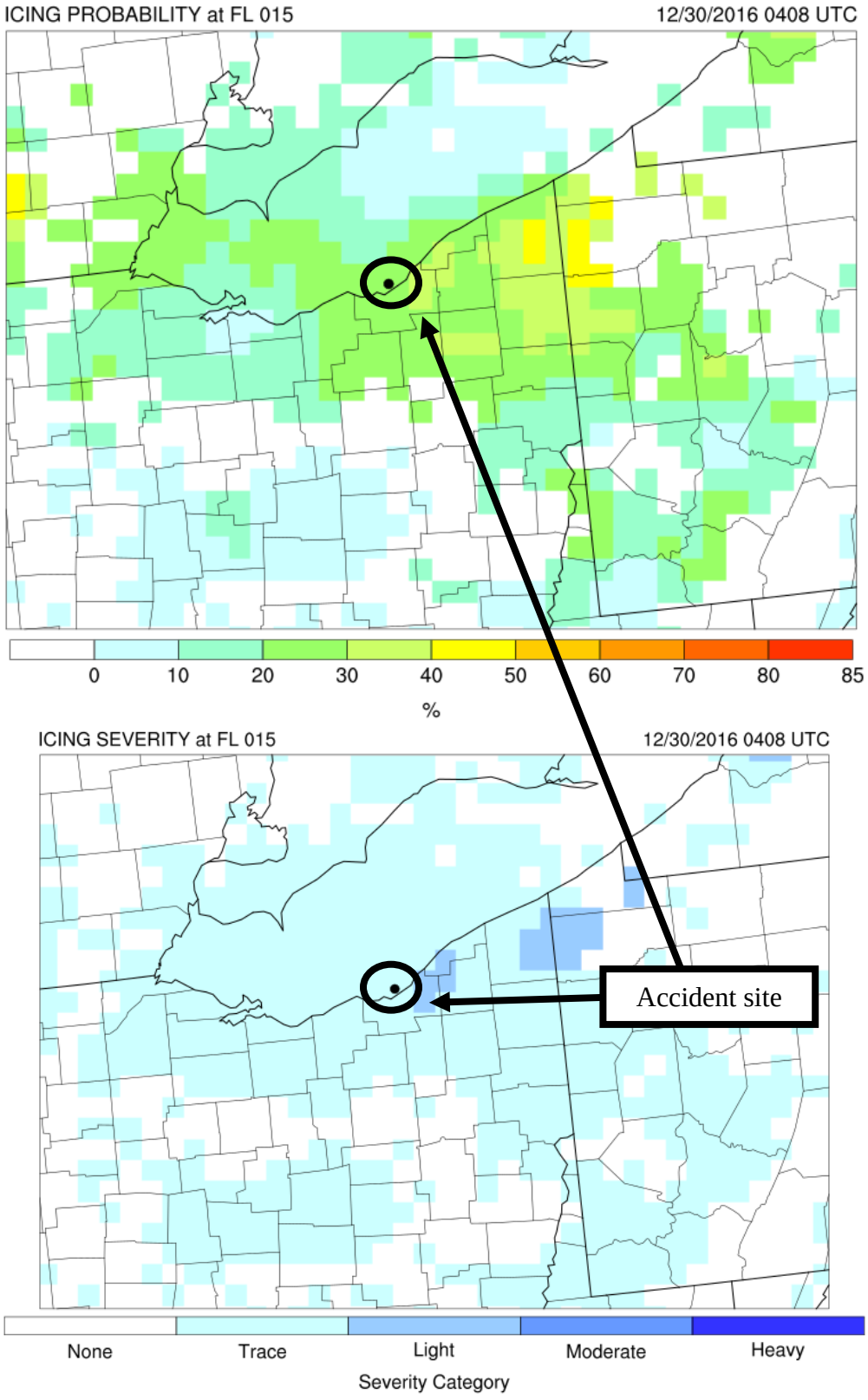

Figure 18 – (top) CIP probability of icing at 1,500 feet msl and (bottom) CIP severity of icing at 1,500 feet msl valid for 2300 EST

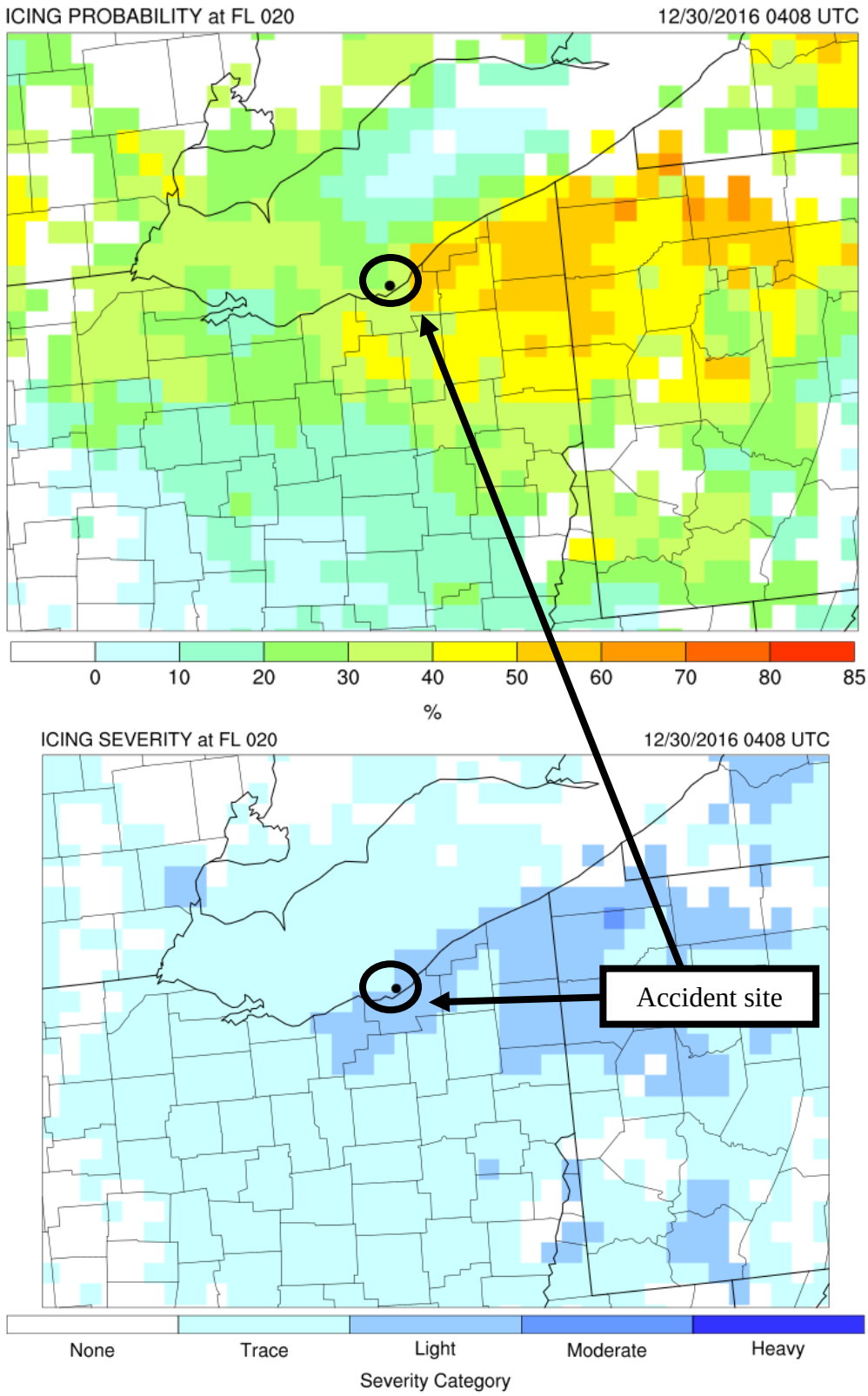

Figure 19 – (top) CIP probability of icing at 2,000 feet msl and (bottom) CIP severity of icing at 2,000 feet msl valid for 2300 EST

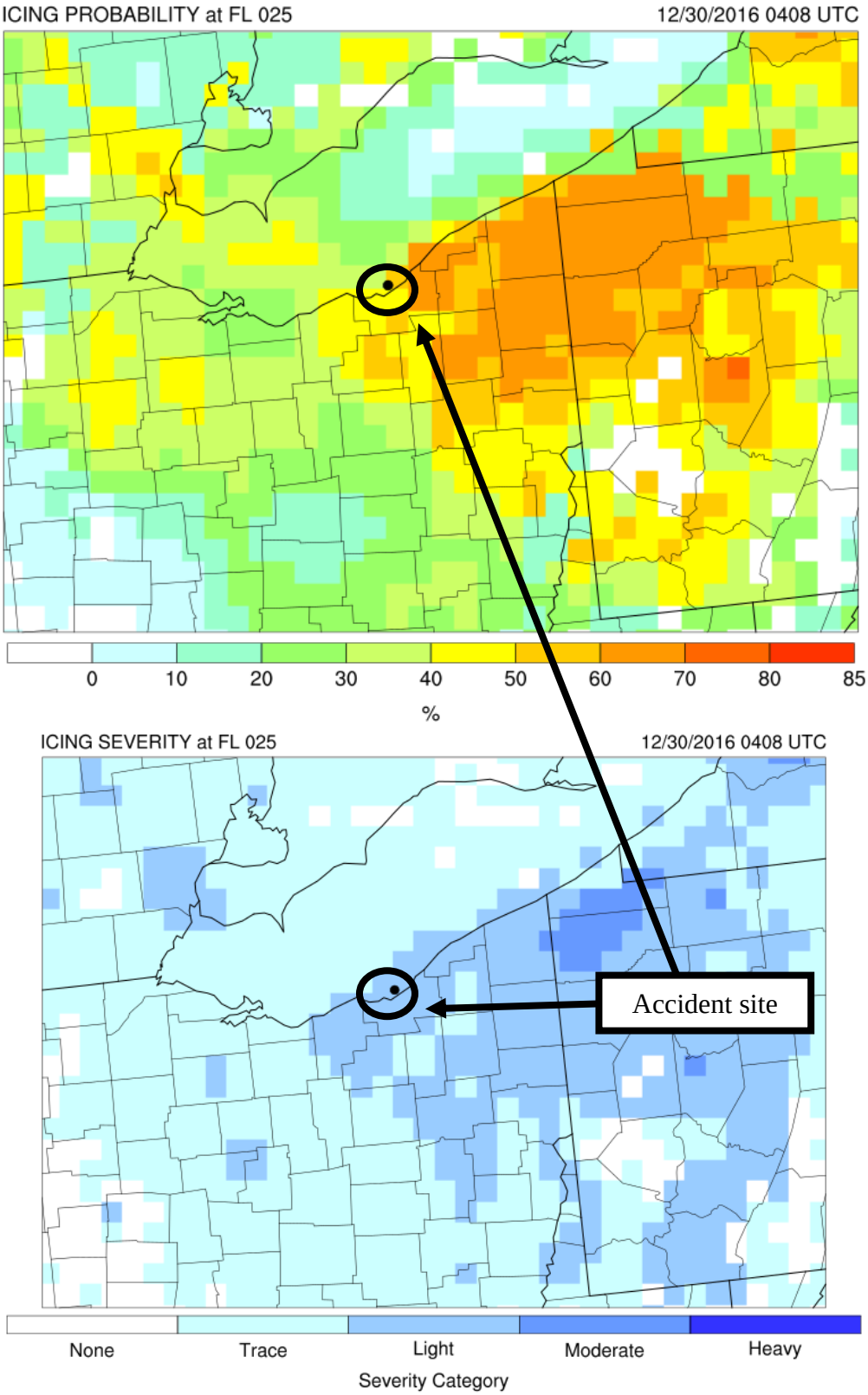

Figure 20 – (top) CIP probability of icing at 2,500 feet msl and (bottom) CIP severity of icing at 2,500 feet msl valid for 2300 EST

16.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on December 29, 2016, indicated the following:

SUN	
Begin civil twilight	0721 EST
Sunrise	0753 EST
Sun transit	1229 EST
Sunset	1705 EST
End civil twilight	1737 EST

MOON	
Moonrise	0751 EST
Moon transit	1250 EST
Moonset	1749 EST

The Moon was set around the accident site at the accident time.

17.0 Lake Effect Snow[29]

Given the relatively cold air (sections 1.2 and 3, figures 2 and 3) moving over the warmer water of Lake Erie, lake effect snow or lake enhanced snow conditions were likely near the departure location and accident site around the accident time. Lake effect snow or lake-enhanced snow occurs when relatively colder air below 10,000 feet moves across the relatively warmer water of a sufficiently large enough lake (figure 21). Lake Erie is a sufficiently large enough lake to help produce lake effect snow and the wind direction was favorable for lake effect snow or lake enhanced snow. There was a NOAA water temperature gauge[30] near Cleveland, Ohio, that reported the water temperature as 38.5° F (~3.6° C) at the accident time (figure 22). The 850-hPa temperature was reported as -9.5° C (sections 1.2 and 4). For lake effect snow or lake-enhanced snow to occur a difference of 13.0 C is typically needed between the lake water temperature and the 850-hPa temperature with a uniform wind direction from the surface to 850- to 700-hPa (attachment 7). The Lake Erie water temperature near Cleveland, Ohio, and the 850-hPa temperature were sufficiently far apart enough for lake effect snow or lake enhanced snow to occur.

[29] More resource can be found at: http://www.nws.noaa.gov/om/winter/lake_effect_snow.shtml
[30] https://tidesandcurrents.noaa.gov/physocean.html?id=9063063

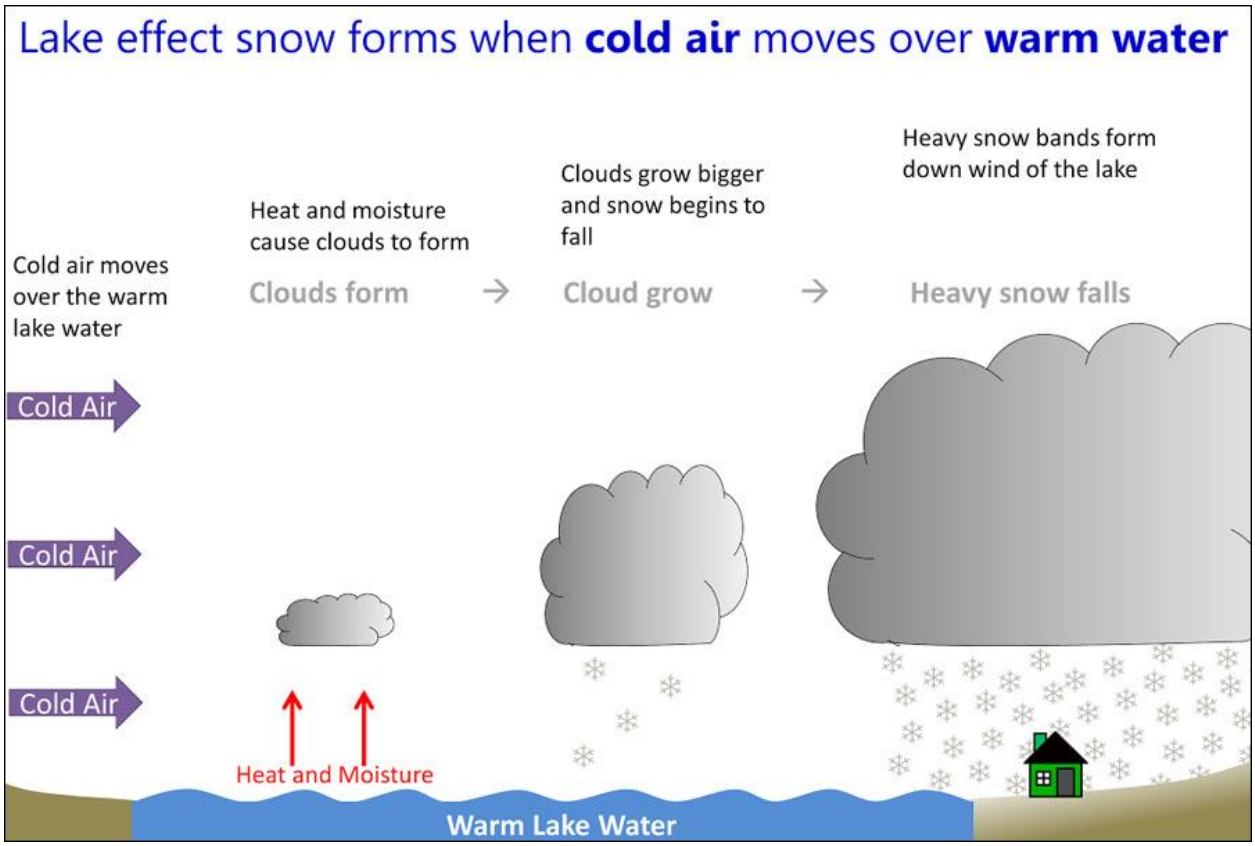

Figure 21 – Lake effect snow diagram

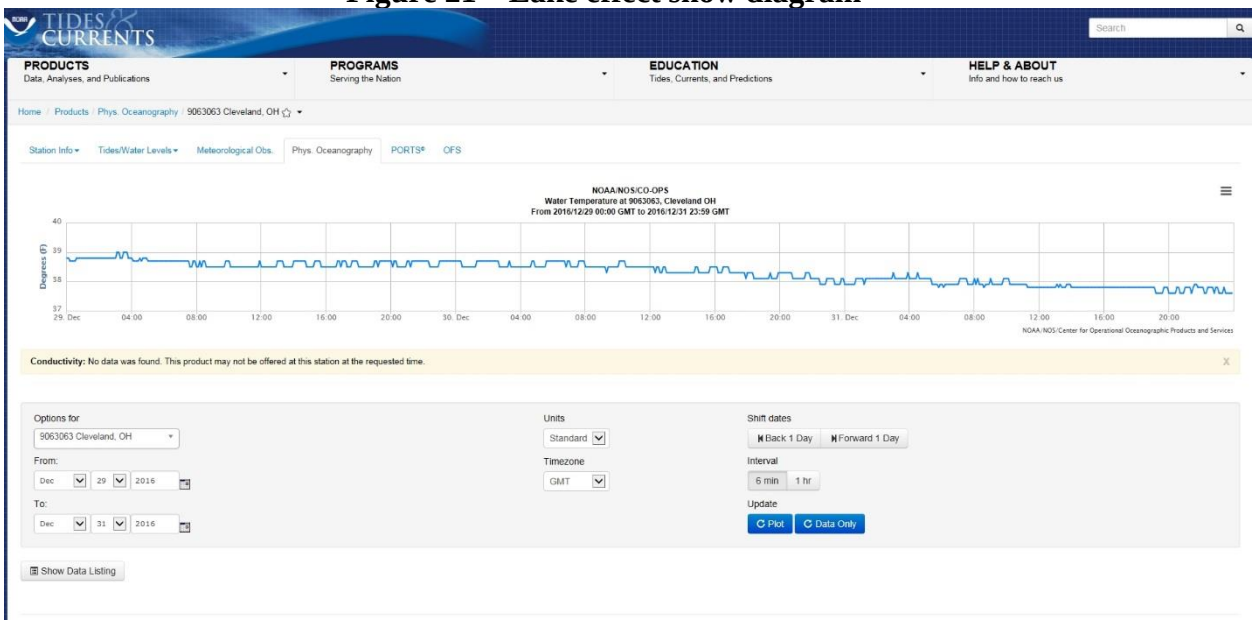

Figure 22 – NOAA water temperature gauge at station 9063063

E. LIST OF ATTACHMENTS

Attachment 1 – Animation of GOES-13 infrared imagery from 2215 EST to 0000 EST, December 30

Attachment 2 – Animation of KCLE WSR-88D base reflectivity images for the 0.5° elevation scans initiated from 2158 to 2324 EST

Attachment 3 – Text LMFS weather briefing information from 1449 EST

Attachment 4 – Text and graphical ForeFlight Mobile weather briefing information from 1449 EST

Attachment 5 – Weather briefing information

Attachment 6 – CIP/FIP data for 2200 and 2300 EST around the accident site

Attachment 7 – Lake effect snow and lake enhanced snow journal article

Submitted by:

_____

Paul Suffern
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