



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

April 18, 2017

Weather Study

METEOROLOGY

DCA17FR003

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A. ACCIDENT

Location: Philadelphia, Pennsylvania
Date: January 4, 2017
Time: 1247 eastern standard time
1747 Coordinated Universal Time (UTC)
Vehicles: SEPTA trolley collision

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 January 4, 2017, 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 39.9601° N, longitude 75.1966° 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 Advisory Circular "Aviation Weather Services", AC 00-45H.

1.1 Surface Analysis Chart

The NWS Surface Analysis Chart for 1300 EST is provided as figure 1 with the approximate location of the accident site marked within the red circle. The chart depicted a cold front stretching from central North Carolina northeastward into eastern New York. The cold front was located just east of the accident site at 1300 EST. The station models around the accident site depicted air temperatures in the low to mid 50's degrees Fahrenheit (°F), dew point temperatures in the low 40's °F, a west wind between 10 and 15 knots, and mostly clear skies.

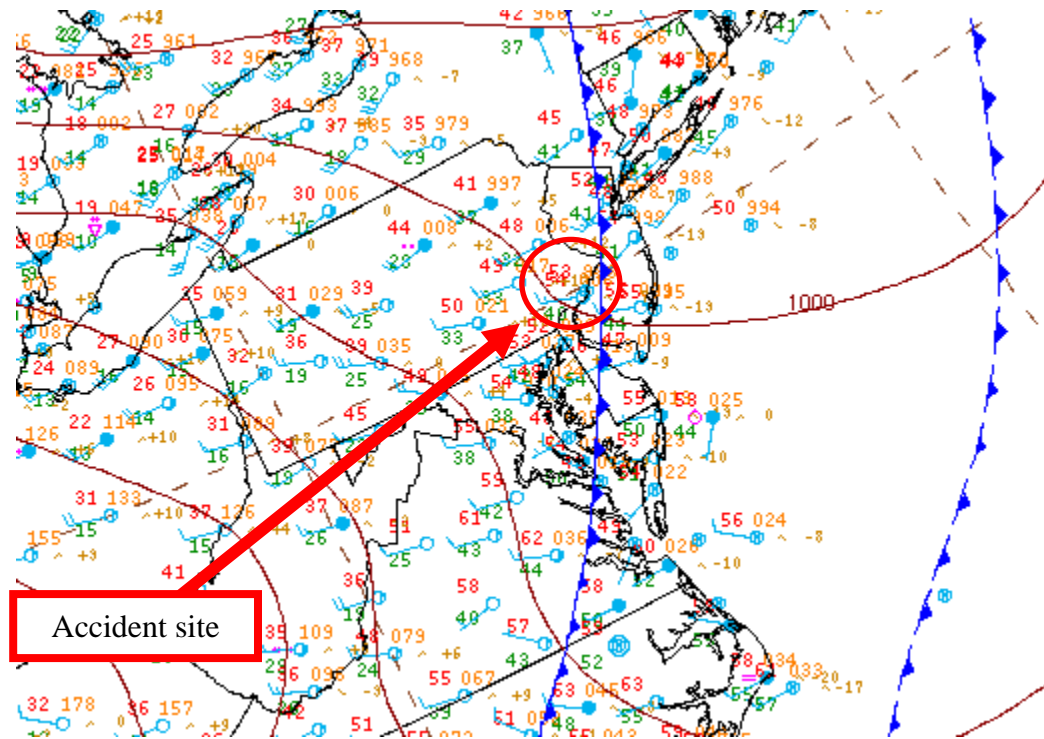


Figure 1 – NWS Surface Analysis Chart for 1300 EST

1.2 Upper Air Charts

The NWS Storm Prediction Center (SPC) Constant Pressure Charts for 0700 EST at 925-, 850-, 700-, 500-, and 300-hectopascals (hPa) are presented in figures 2 through 6. The accident site was located just east of low-level troughs¹ at 925-, and 850-hPa (figures 2 and 3). The accident site was located in between mid-level troughs at 700- and 500-hPa (figures 4 and 5). Areas near troughs are often favored locations for surface frontal boundaries, enhanced vertical motion, clouds, and precipitation. There was a west wind of 20 to 30 knots at 925-hPa (figure 2). The wind became southwesterly by 700-hPa and the wind speed increased to 45 knots (figure 4). By 500-hPa, the wind was still from the southwest, now at 55 knots (figure 5), with the wind speed increasing to 70 knots by 300-hPa (figure 6).

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

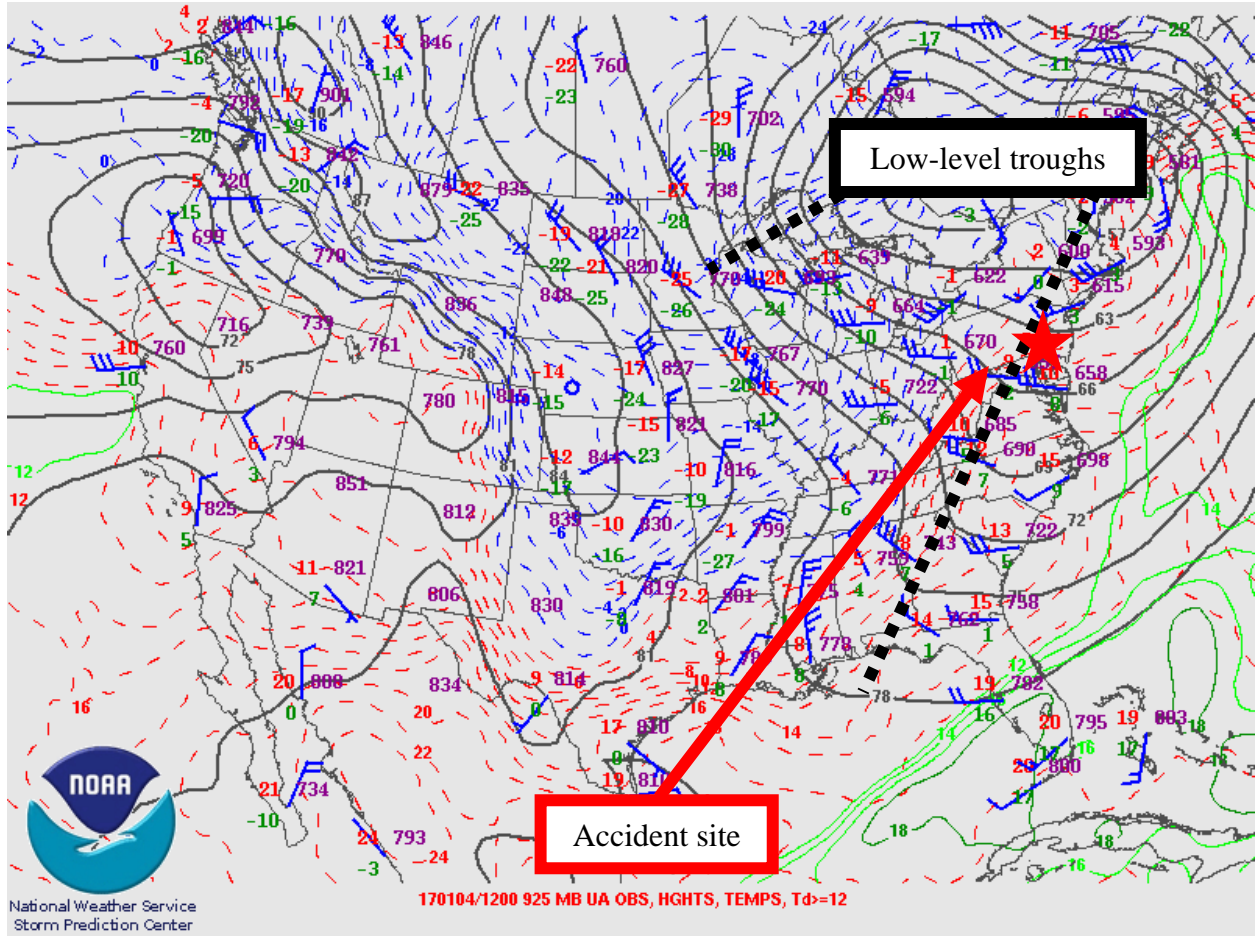


Figure 2 – 925-hPa Constant Pressure Chart for 0700 EST

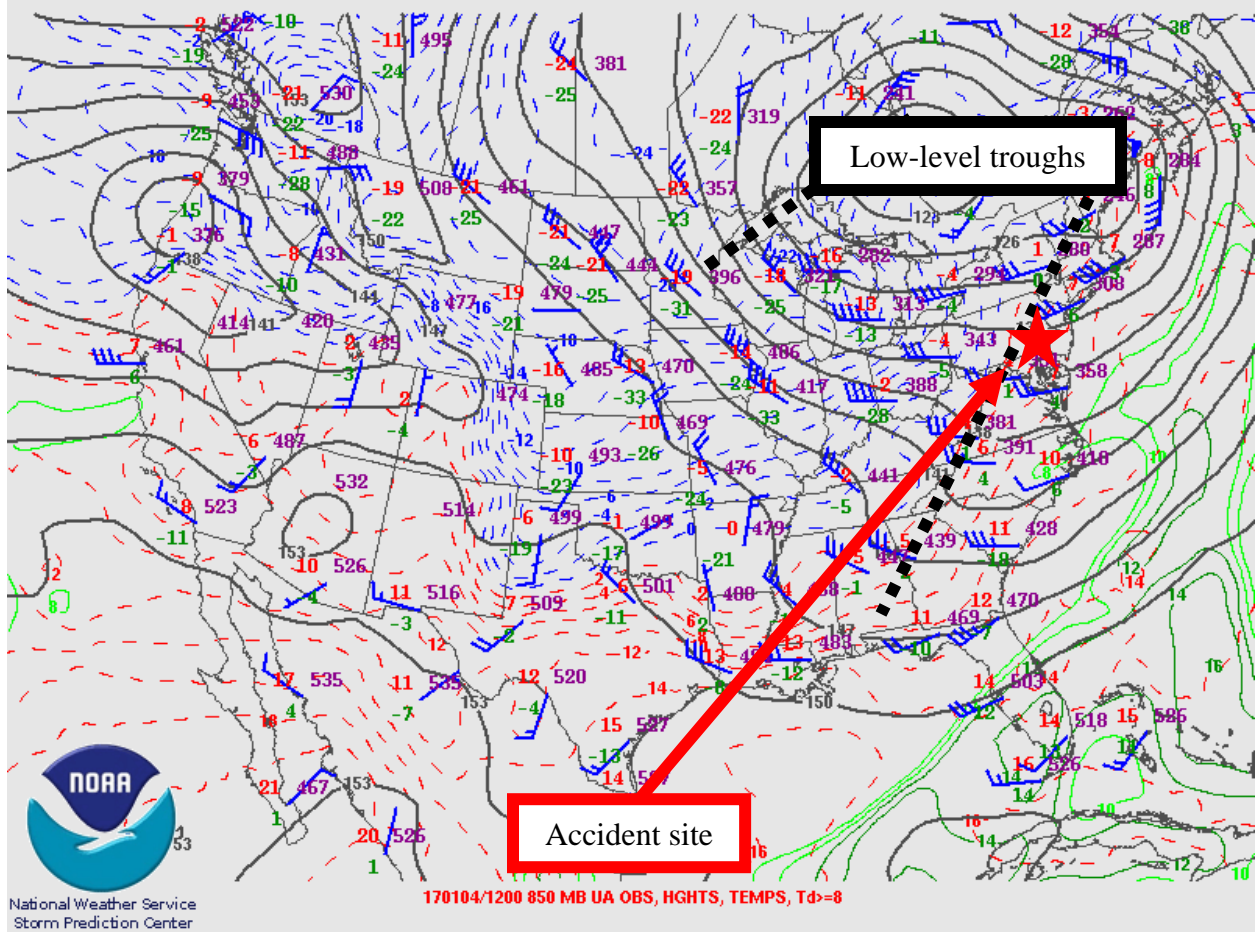


Figure 3 – 850-hPa Constant Pressure Chart for 0700 EST

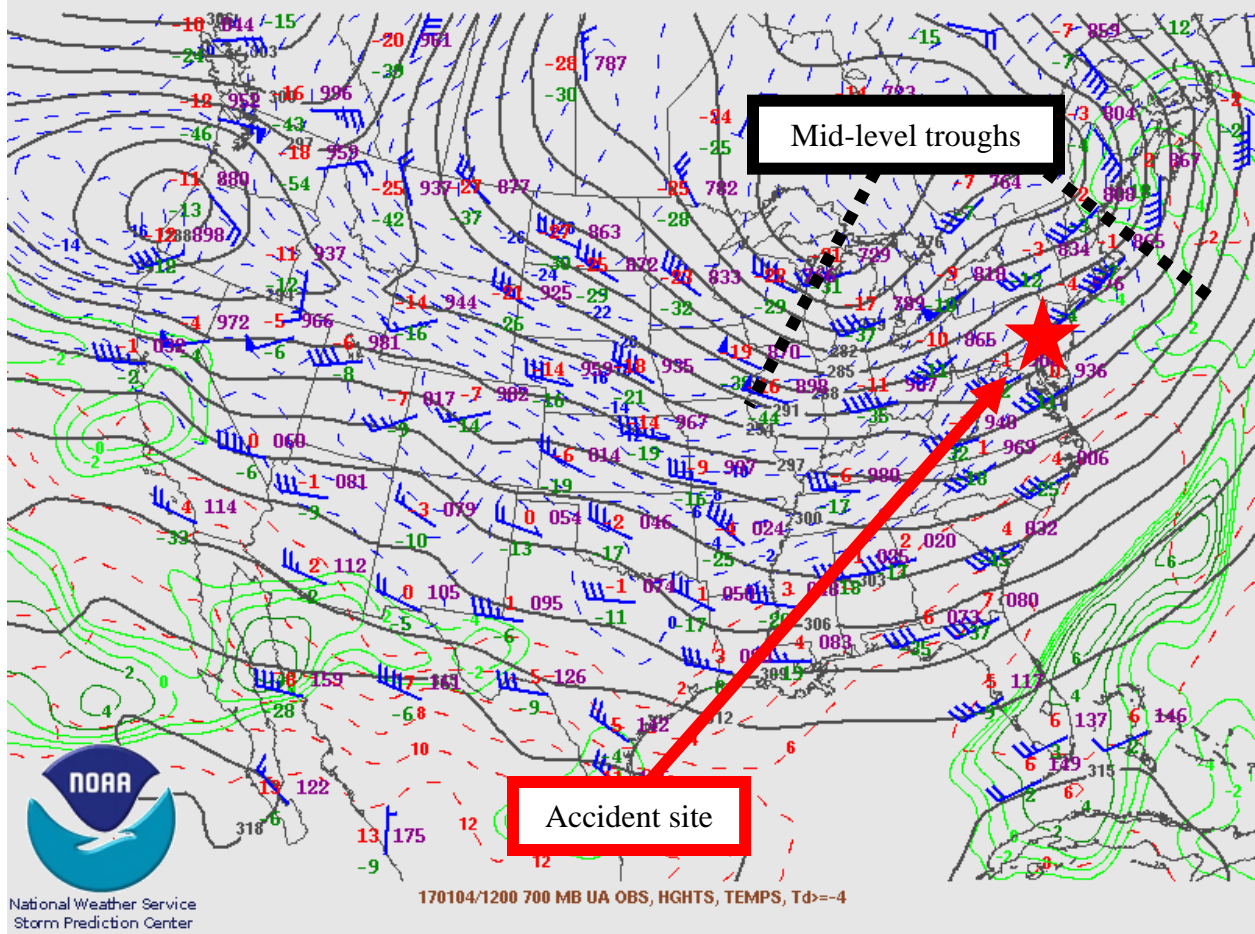


Figure 4 – 700-hPa Constant Pressure Chart for 0700 EST

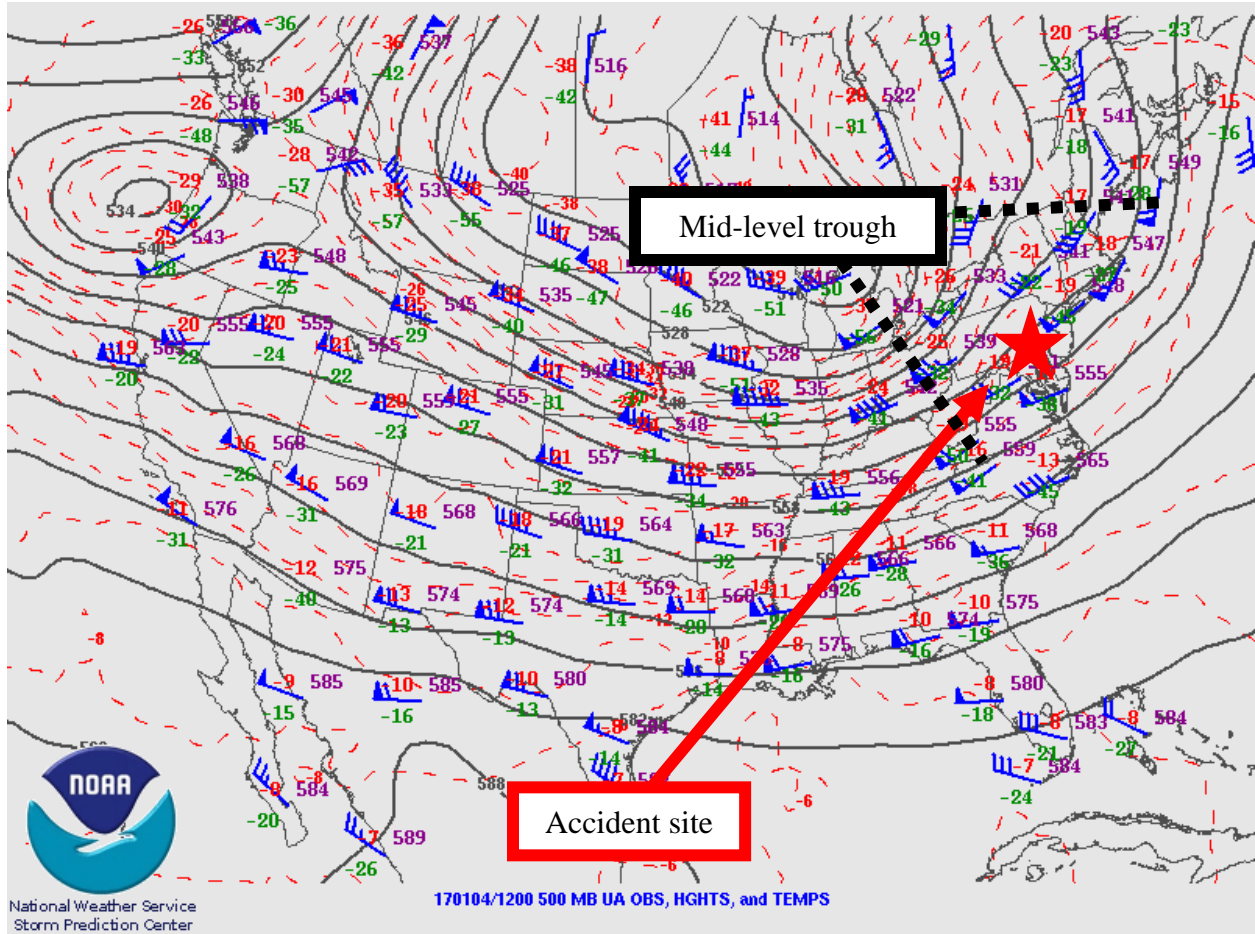


Figure 5 – 500-hPa Constant Pressure Chart for 0700 EST

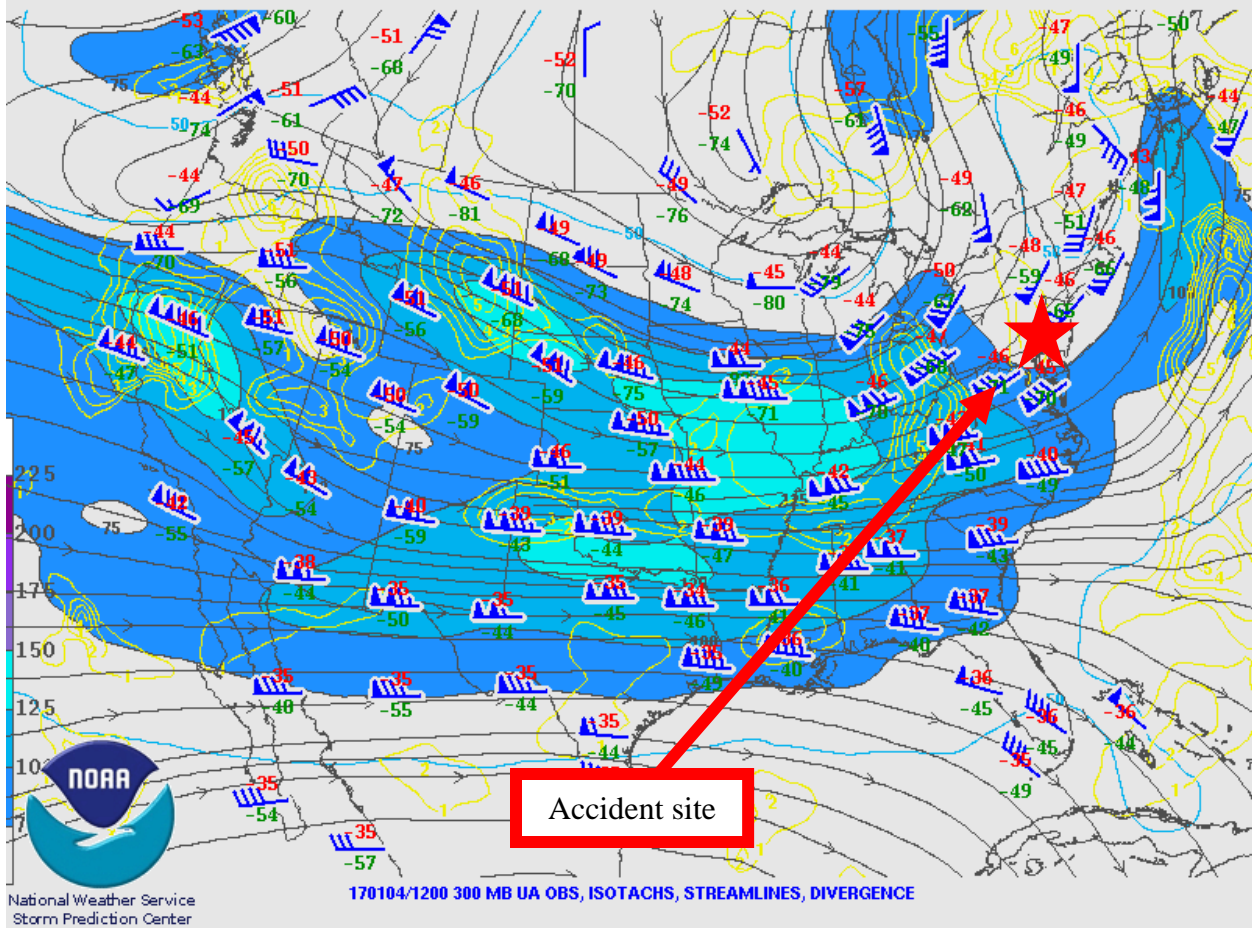


Figure 6 – 300-hPa Constant Pressure Chart for 0700 EST

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 MesoWest² local area map with the accident site and the closest weather reporting locations marked.

² <http://mesowest.utah.edu/>

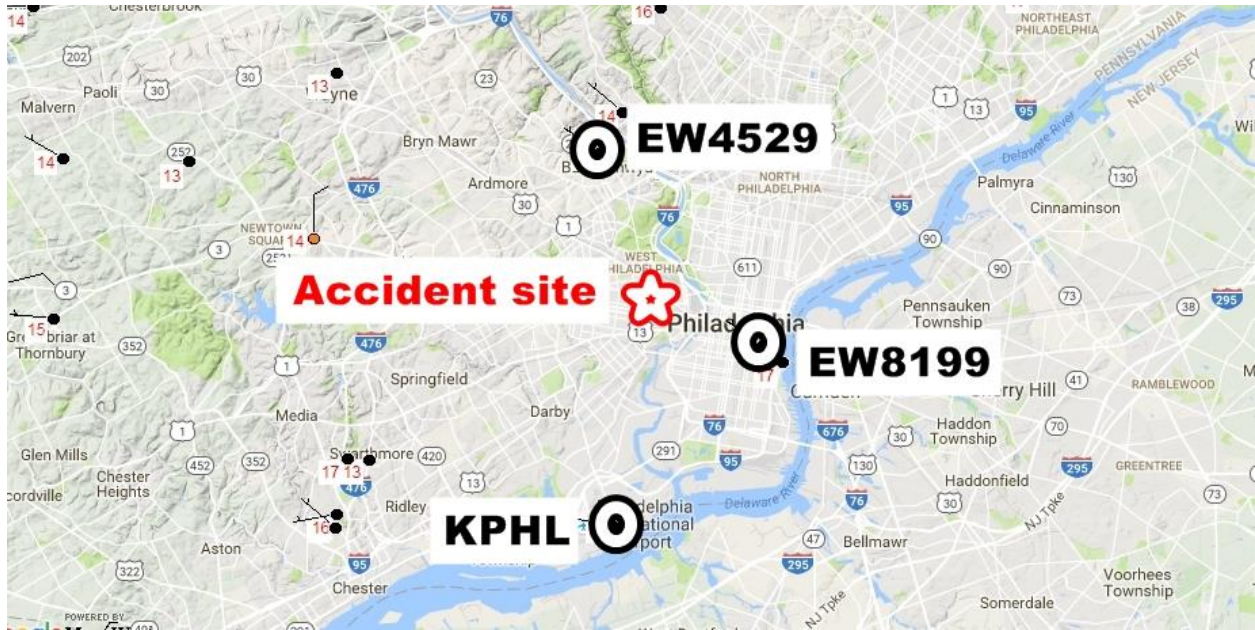


Figure 7 – Local area map of accident area with the location of the accident site and surface observation sites

Philadelphia International Airport (KPHL) was the closest official weather station to the accident site, and was located 5 miles southwest of Philadelphia, Pennsylvania. KPHL had an Automated Surface Observing System (ASOS³) whose reports were supplemented by an official human observer. KPHL was located 6 miles south of the accident site, at an elevation of 36 feet, and had a 10° westerly magnetic variation⁴ (figure 7). The following observations were taken and disseminated during the times surrounding the accident:⁵

- [1001 EST] SPECI KPHL 041501Z 21007KT 5SM BR FEW004 SCT012 SCT210 BKN250
08/07 A2957 RMK AO2 T00830072=
- [1022 EST] SPECI KPHL 041522Z 23009KT 5SM BR SCT007 BKN013 BKN210 OVC250
08/07 A2958 RMK AO2 T00830067=
- [1035 EST] SPECI KPHL 041535Z 23009KT 6SM BR SCT008 BKN015 BKN021 BKN210
OVC250 09/07 A2959 RMK AO2 T00890072=
- [1045 EST] SPECI KPHL 041545Z 23011KT 7SM BKN009 BKN015 OVC021 09/07
A2960 RMK AO2 T00890072=

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

⁴ Magnetic variation – The angle (at a particular location) between magnetic north and true north. 1980, latest measurement taken from <http://www.airnav.com/airport/KPHL>

⁵ The bold sections in this NWS product and the rest of products in this report are intended to highlight the sections that directly reference the weather conditions that 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.

[1054 EST] METAR KPHL 041554Z 22007KT 180V250 7SM BKN007 OVC250 09/07
A2959 RMK AO2 SLP020 T00940072=

**[1107 EST] SPECI KPHL 041607Z 24008KT 7SM SCT007 SCT020 OVC250 08/07
A2959 RMK AO2 T00830072=**

**[1154 EST] METAR KPHL 041654Z 25009KT 9SM FEW008 SCT037 BKN047 BKN250
10/08 A2957 RMK AO2 SLP013 T01000078=**

ACCIDENT TIME 1247 EST

**[1254 EST] METAR KPHL 041754Z 29015G22KT 10SM SCT031 SCT040 BKN085
BKN170 BKN250 12/04 A2955 RMK AO2 SLP006 T01220044 10122
20067 58007=**

**[1354 EST] METAR KPHL 041854Z 29017G24KT 10SM FEW038 SCT047 SCT090
BKN170 BKN250 12/02 A2955 RMK AO2 SLP008 T01170022=**

[1454 EST] METAR KPHL 041954Z 29021G26KT 10SM FEW045 SCT055 SCT170 SCT250
12/00 A2956 RMK AO2 PK WND 28026/1953 SLP011 T01220000=

[1554 EST] METAR KPHL 042054Z 28013G23KT 10SM SCT060 SCT160 SCT250 11/M02
A2959 RMK AO2 PK WND 30029/2035 SLP021 T01111017 53015=

KPHL weather at 1107 EST, wind from 240° at 8 knots, 7 miles visibility, scattered clouds at 700 feet above ground level (agl), scattered clouds at 2,000 feet agl, an overcast ceiling at 25,000 feet agl, temperature of 8° Celsius (C), dew point temperature of 7° C, and an altimeter setting of 29.59 inches of mercury. Remarks, station with a precipitation discriminator, temperature 8.3° C, dew point temperature 7.2° C.

KPHL weather at 1154 EST, wind from 250° at 9 knots, 9 miles visibility, few clouds at 800 feet agl, scattered clouds at 3,700 feet, broken ceiling at 4,700 feet agl, broken skies at 25,000 feet agl, temperature of 10° C, dew point temperature of 8° C, and an altimeter setting of 29.57 inches of mercury. Remarks, station with a precipitation discriminator, sea level pressure 1001.3 hPa, temperature 10.0° C, dew point temperature 7.8° C.

KPHL weather at 1254 EST, wind from 290° at 15 knots with gusts to 22 knots, 10 miles visibility, scattered clouds at 3,100 feet agl, scattered clouds at 4,000 feet, broken ceiling at 8,500 feet agl, broken skies at 17,000 feet agl, broken skies at 25,000 feet agl, temperature of 12° C, dew point temperature of 4° C, and an altimeter setting of 29.55 inches of mercury. Remarks, station with a precipitation discriminator, sea level pressure 1000.6 hPa, temperature 12.2° C, dew point temperature 4.4° C, 6-hourly maximum temperature of 12.2° C, 6-hourly minimum temperature of 6.7° C, 3-hourly pressure decrease of 0.7 hPa.

KPHL weather at 1354 EST, wind from 290° at 17 knots with gusts to 24 knots, 10 miles visibility, few clouds at 3,800 feet agl, scattered clouds at 4,700 feet, scattered clouds at 9,000 feet agl, broken ceiling at 17,000 feet agl, broken skies at 25,000 feet agl, temperature of 12° C, dew point temperature of 2° C, and an altimeter setting of 29.55 inches of mercury. Remarks, station with a precipitation discriminator, sea level pressure 1000.8 hPa, temperature 11.7° C, dew point temperature 2.2° C.

EW8199 Philadelphia (EW8199) was an Automatic Position Reporting System as a WX NET/Citizen Weather Observer Program (APRSWXNET/CWOP) mesonet station and was the closest non-official surface observation site to the accident site located 2 miles east-southeast of the accident site at an elevation of 39 feet (see figure 7). Figure 8 contains the observations surrounding the accident time:

# STATION: E8199									
# STATION NAME: EW8199 Philadelphia									
# LATITUDE: 39.94367									
# LONGITUDE: -75.15100									
# ELEVATION [ft]: 39									
# STATE: PA									
Station_ID	Date_Time	altimeter	air_temp	relative_humidity	wind_speed	wind_dir	wind_gust	precip_accum	dew_point
		INHG	Fahrenheit	%	Miles/hour	Degrees	Miles/hour	Inches	Fahrenheit
E8199	01/04/2017 09:17 EST	29.56	48	88	4	274	7	0	44.58
E8199	01/04/2017 09:32 EST	29.57	48	88	4	227	8.99	0	44.58
E8199	01/04/2017 09:47 EST	29.58	48	88	4.99	202	8.99	0	44.58
E8199	01/04/2017 10:02 EST	29.58	48	89	4	219	8.01	0	44.88
E8199	01/04/2017 10:17 EST	29.58	48	90	4	233	8.01	0	45.17
E8199	01/04/2017 10:33 EST	29.59	48	90	3	250	8.01	0	45.17
E8199	01/04/2017 10:47 EST	29.6	48.99	89	3	295	5.99	0	45.85
E8199	01/04/2017 11:02 EST	29.6	48	88	1.01	258	5.99	0	44.58
E8199	01/04/2017 11:17 EST	29.59	48.99	90	2.01	224	8.01	0	46.15
E8199	01/04/2017 11:32 EST	29.59	50	88	2.01	248	10	0	46.55
E8199	01/04/2017 11:47 EST	29.58	51.01	84	3	294	8.99	0	46.29
E8199	01/04/2017 12:02 EST	29.58	51.01	84	3	315	7	0	46.29
E8199	01/04/2017 12:18 EST	29.57	52	81	2.01	324	8.99	0	46.29
E8199	01/04/2017 12:33 EST	29.56	53.01	68	7	326	18.99	0.01	42.63
E8199	01/04/2017 12:48 EST	29.56	53.01	65	7	35	14.99	0.01	41.45
E8199	01/04/2017 13:03 EST	29.56	54	64	8.99	340	21	0.01	41.99
E8199	01/04/2017 13:18 EST	29.56	53.01	62	5.99	287	18.99	0.01	40.22
E8199	01/04/2017 13:33 EST	29.56	53.01	61	8.01	324	17	0.01	39.8
E8199	01/04/2017 13:48 EST	29.57	53.01	59	4.99	304	11.01	0.01	38.94
E8199	01/04/2017 14:03 EST	29.56	54	56	4	277	15.99	0.01	38.52
E8199	01/04/2017 14:18 EST	29.56	55	52	4	303	14.99	0.01	37.55
E8199	01/04/2017 14:33 EST	29.56	54	50	8.01	345	18.01	0.01	35.62
E8199	01/04/2017 14:48 EST	29.57	53.01	52	5.99	303	14.99	0.01	35.7
E8199	01/04/2017 15:03 EST	29.58	54	49	8.01	341	15.99	0.01	35.11
E8199	01/04/2017 15:18 EST	29.59	52	49	7	347	17	0.01	33.27
E8199	01/04/2017 15:33 EST	29.59	52	45	7	324	21	0.01	31.14
E8199	01/04/2017 15:48 EST	29.59	52	44	10	304	22.01	0.01	30.58
E8199	01/04/2017 16:03 EST	29.6	51.01	41	8.01	258	25.99	0.01	27.94

Figure 8 – List of observations from EW8199 surrounding the accident time

EW8199 weather at 1233 EST was reported as wind from 326° at 7 miles-per-hour (mph) (6.08 knots) with gusts to 18.99 mph (16.50 knots), temperature of 53.01° F (11.67° C), and a dew point temperature of 42.63° F (5.91° C).

EW8199 weather at 1248 EST was reported as wind from 035° at 7 mph (6.08 knots) with gusts to 14.99 mph (13.03 knots), temperature of 53.01° F (11.67° C), and a dew point temperature of 41.45° F (5.25° C).

EW8199 weather at 1303 EST was reported as wind from 340° at 8.99 mph (7.81 knots) with gusts to 21 mph (18.25 knots), temperature of 54° F (12.22° C), and a dew point temperature of 41.99° F (5.55° C).

EW4529 Bala Cynwyd (EW4529) was an Automatic Position Reporting System as a WX NET/Citizen Weather Observer Program (APRSWXNET/CWOP) mesonet station and was the next closest non-official surface observation site to the accident site located 4 miles north-northwest of the accident site at an elevation of 246 feet (see figure 7). Figure 9 contains the observations surrounding the accident time:

Station_ID	Date_Time	altimeter	air_temp	relative_humidity	wind_speed	wind_direction	wind_gust_s	precip_accum_since_local_midnight	dew_point_temperature_set_1d
		INHg	Fahrenheit	%	Miles/hour	Degrees	Miles/hour	Inches	Fahrenheit
E4529	01/04/2017 10:58 EST	29.63	50	88	0		3	0.01	46.55
E4529	01/04/2017 11:03 EST	29.63	50	89	0		3	0.01	46.85
E4529	01/04/2017 11:08 EST	29.63	51.01	87	1.01	299	3	0.01	47.24
E4529	01/04/2017 11:13 EST	29.63	51.01	86	1.01	297	4.99	0.01	46.93
E4529	01/04/2017 11:18 EST	29.62	51.01	86	1.01	304	4.99	0.01	46.93
E4529	01/04/2017 11:23 EST	29.62	52	83	1.01	281	4.99	0.01	46.94
E4529	01/04/2017 11:28 EST	29.62	52	81	2.01	228	7	0.01	46.29
E4529	01/04/2017 11:33 EST	29.62	53.01	81	0		7	0.01	47.28
E4529	01/04/2017 11:38 EST	29.62	53.01	78	1.01	13	4	0.01	46.27
E4529	01/04/2017 11:43 EST	29.62	53.01	78	1.01	113	4.99	0.01	46.27
E4529	01/04/2017 11:48 EST	29.62	53.01	77	1.01	355	5.99	0.01	45.92
E4529	01/04/2017 11:53 EST	29.61	53.01	74	3	207	7	0.01	44.86
E4529	01/04/2017 11:58 EST	29.61	53.01	74	1.01	113	7	0.01	44.86
E4529	01/04/2017 12:03 EST	29.6	53.01	73	1.01	302	7	0.01	44.5
E4529	01/04/2017 12:08 EST	29.6	53.01	74	1.01	6	5.99	0.01	44.86
E4529	01/04/2017 12:13 EST	29.6	53.01	74	1.01	11	4	0.01	44.86
E4529	01/04/2017 12:18 EST	29.6	53.01	74	1.01	198	4	0.01	44.86
E4529	01/04/2017 12:23 EST	29.6	52	73	1.01	199	4	0.01	43.53
E4529	01/04/2017 12:28 EST	29.6	52	74	0		4	0.01	43.89
E4529	01/04/2017 12:33 EST	29.59	52	74	1.01	249	4	0.01	43.89
E4529	01/04/2017 12:38 EST	29.59	52	73	1.01	340	11.01	0.01	43.53
E4529	01/04/2017 12:43 EST	29.6	52	72	2.01	91	8.01	0.01	43.17
E4529	01/04/2017 12:48 EST	29.59	52	72	1.01	319	8.01	0.01	43.17
E4529	01/04/2017 12:53 EST	29.59	52	72	1.01	349	4.99	0.01	43.17
E4529	01/04/2017 12:58 EST	29.59	52	70	2.01	337	8.99	0.01	42.42
E4529	01/04/2017 13:03 EST	29.59	52	70	2.01	348	8.99	0.01	42.42
E4529	01/04/2017 13:08 EST	29.59	52	69	1.01	200	12.01	0.01	42.05
E4529	01/04/2017 13:13 EST	29.59	52	67	3	330	8.99	0.01	41.28

Figure 9 – List of observations from EW4529 surrounding the accident time

EW4529 weather at 1243 EST was reported as wind from 091° at 2.01 mph (1.75 knots) with gusts to 8.01 mph (6.96 knots), temperature of 52° F (11.11° C), and a dew point temperature of 43.17° F (6.21° C).

EW4529 weather at 1248 EST was reported as wind from 319° at 1.01 mph (0.87 knots) with gusts to 8.01 mph (6.96 knots), temperature of 52° F (11.11° C), and a dew point temperature of 43.17° F (6.21° C).

EW4529 weather at 1253 EST was reported as wind from 349° at 1.01 mph (0.87 knots) with gusts to 4.99 mph (4.34 knots), temperature of 52° F (11.11° C), and a dew point temperature of 43.17° F (6.21° C).

3.1 One Minute Wind Observations

The one-minute KPHL 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

directions⁶. 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 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)
1225	1725	246	9	248	10
1226	1726	246	9	245	10
1227	1727	245	9	243	11
1228	1728	246	9	248	11
1229	1729	249	9	254	9
1230	1730	254	8	252	9
1231	1731	256	7	255	8
1232	1732	260	7	254	8
1233	1733	269	7	274	8
1234	1734	276	7	273	9
1235	1735	285	7	276	8
1236	1736	284	6	278	8
1237	1737	276	7	272	9
1238	1738	279	8	285	10
1239	1739	284	8	290	11
1240	1740	277	8	291	11
1241	1741	267	8	269	9
1242	1742	273	8	282	9
1243	1743	274	9	256	14
1244	1744	271	11	278	15
1245	1745	273	12	274	15
1246	1746	269	14	267	19
1247	1747	268	16	265	19
1248	1748	272	15	278	17
1249	1749	280	13	274	15
1250	1750	286	12	295	17
1251	1751	282	13	267	17
1252	1752	279	15	280	22
1253	1753	285	15	288	20
1254	1754	289	15	282	20
1255	1755	288	15	281	19
1256	1756	287	14	291	15
1257	1757	290	13	285	18

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

At 1246 EST, KPHL reported the two-minute average wind from 269° at 14 knots, a five-second maximum average wind from 267° at 19 knots.

At 1247 EST, KPHL reported the two-minute average wind from 268° at 16 knots, a five-second maximum average wind from 265° at 19 knots

At 1248 EST, KPHL reported the two-minute average wind from 272° at 15 knots, a five-second maximum average wind from 278° at 17 knots

The observations from KPHL, EW4529, and EW8199 surrounding the accident time indicated no restrictions to visibility or ceilings and no precipitation. The surface wind gusts and sustained wind speeds all increased right around the accident time with gusts of 19 knots observed at KPHL and 18.25 knots at EW8199.

4.0 Upper Air Data

A High-Resolution Rapid Refresh (HRRR)⁷ model sounding was created for the accident site for 1300 EST. The 1300 EST sounding was plotted on a standard Skew-T log P diagram⁸ with the derived stability parameters included in figure 10 (with data from the surface to 700-hPa, or 10,000 feet msl.) This data was analyzed utilizing the RAOB⁹ software package. The sounding depicted the lifted condensation level (LCL)¹⁰ at 2,064 feet msl, a convective condensation level (CCL)¹¹ of 3,593 feet, and a level of free convection (LFC)¹² at 2,064 feet. The freezing level was at 4,827 feet. The precipitable water value was 0.57 inches.

⁷ 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.

⁸ 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.

⁹ RAOB – (The complete Rawinsonde Observation program) is an interactive sounding analysis program developed by Environmental Research Services, Matamoras, Pennsylvania.

¹⁰ Lifting Condensation Level (LCL) - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.

¹¹ 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.

¹² 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.

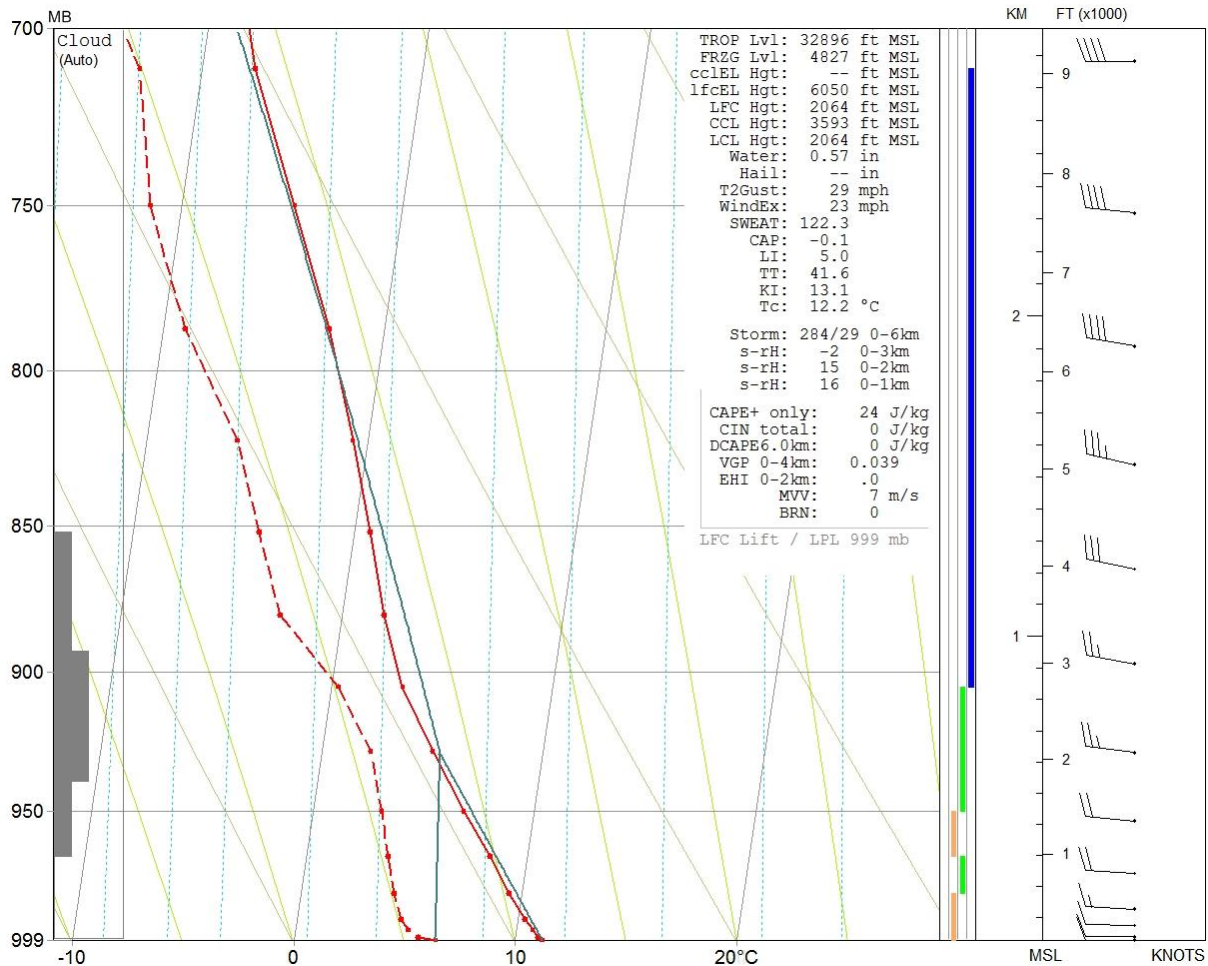


Figure 10 – 1300 EST HRRR sounding for the accident site

The 1300 EST HRRR sounding indicated an unstable to conditionally unstable layer between the surface and 2,800 feet. A stable layer was present from 2,800 feet through 10,000 feet. RAOB indicated that clouds were likely from 1,000 feet through 4,500 feet. There was insufficient moisture in the favored dendritic growth zone between -10° C and -20° C, and all the way to the surface, and therefore precipitation would not be expected at the surface.

The 1300 EST HRRR sounding wind profile indicated a surface wind from 270° at 8 knots with the wind remaining westerly through 10,000 feet. The wind increased in speed to 20 knots by 800 feet. The wind speed remained between 25 to 40 knots between 2,000 and 10,000 feet. Given the unstable to conditionally unstable layer between the surface and 2,800 feet, the strongest surface wind likely would have been 25 knots which was similar to the wind speed observed at KPHL around the accident time.

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 1000 EST through 1600 EST at approximately 15-minute intervals were reviewed, and the closest images to the time of the accident are documented here.

Figure 11 presents the GOES-13 visible imagery from 1245 EST at 2X magnification with the accident site highlighted with a red square. Inspection of the visible imagery indicated scattered to broken skies across eastern Pennsylvania, New Jersey, Delaware, and Maryland with a mixture of both high and low clouds. Figure 12 presents the GOES-13 infrared imagery from 1245 EST at 4X magnification with the accident site highlighted with a red square. Inspection of the infrared imagery indicated abundant cloud cover over and around the accident site at the accident time. The lower brightness temperatures (green colors, higher cloud tops) were located over eastern New York, the western Atlantic Ocean, and southeastern United States. Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 1300 EST HRRR sounding, the approximate cloud-top heights over the accident site were estimated at 7,500 feet at 1245 EST (figure 12).

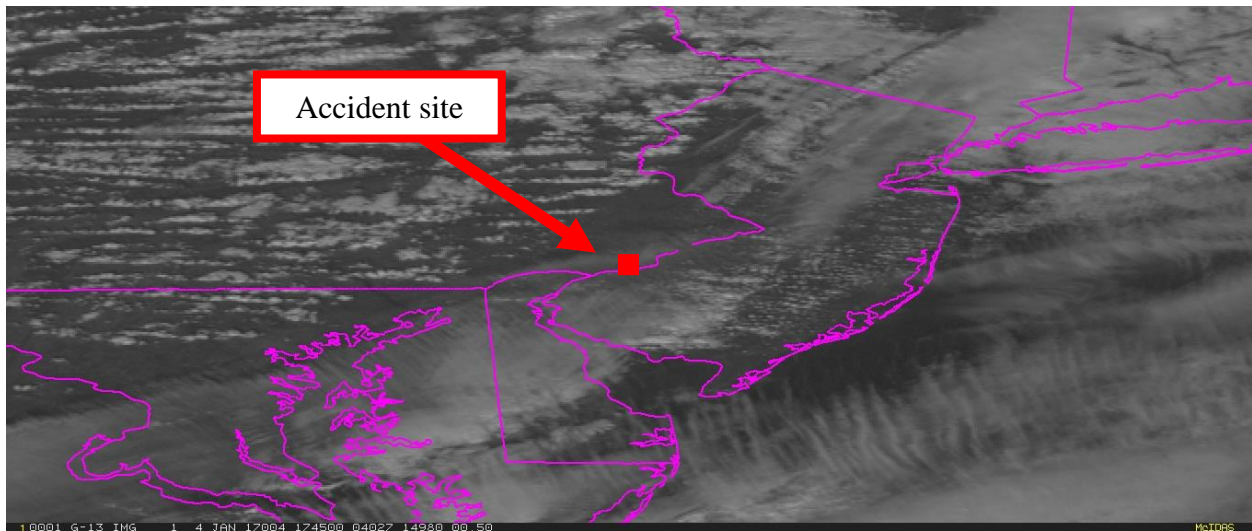


Figure 11 – GOES-13 visible image at 1245 EST

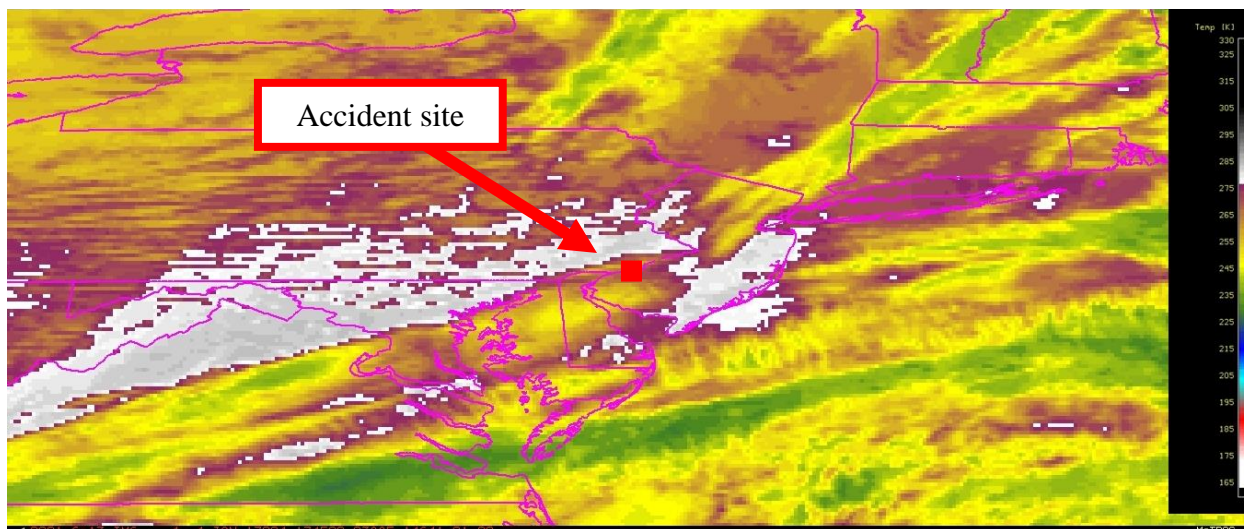


Figure 12 – GOES-13 infrared image at 1245 EST

6.0 Radar Imagery Information

The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)¹³ to the accident site was the Manchester, New Jersey, radar (KDIX), which was located 36 miles east of the accident site at an elevation of 148 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. No precipitation targets were located above the accident site at the accident time.

7.0 NWS Area Forecast Discussion

The NWS Office in Mount Holly, New Jersey, issued the following Area Forecast Discussion (AFD) at 0637 EST (closest AFD to the accident time). The AFD discussed the frontal boundary (section 1.1) moving across the region on the accident day with westerly wind gusts up to 30 mph possible and surface temperatures falling through the afternoon:

186
 FXUS61 KPHI 041137
 AFDPHI

Area Forecast Discussion
 National Weather Service Mount Holly NJ
 637 AM EST Wed Jan 4 2017

.SYNOPSIS...

High pressure will extend into the Mid Atlantic region late today and tonight before weakening. Low pressure will then develop off the Carolina Coast Thursday evening and track northeastward, however it will remain well offshore. A second low pressure system develops

¹³ 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.

along a front over the eastern Gulf of Mexico Friday night into Saturday, then tracks northeastward off the coast of the Southeastern states before moving out to sea later Saturday. A strong area of high pressure will then build in for Monday into Tuesday.

&&

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

The front continues to cross central PA, expected to arrive in the southern Poconos and Berks County within 3 to 4 hours. It should sweep through all of our region by mid day. **The most immediate impacts to our region with the front today will be windy conditions (westerly winds with gusts up to 30 mph possible), temperatures falling through the afternoon, and drier air moving in to the region (by this evening, dew point temperatures should be about 20 degrees lower than they are currently).**

As of 6 AM EST, there was a narrow band of showers immediately following the front. However, high resolution models continue to show that this will dissipate as it gets closer to our region. Since it looks to be mostly lake enhanced, would expect it to dissipate as it gets further from Lake Erie.

On the bright side...the dry air advection and increased low level mixing will help to dissipate the low clouds leaving mostly sunny skies for much of the region by this afternoon.

&&

.SHORT TERM /6 PM THIS EVENING THROUGH 6 AM THURSDAY/...

Cold air advection will continue through the overnight hours. However, breezy conditions are expected to continue through the evening. So although it will be considerably colder than what we've seen the last few nights, radiational cooling will be limited. Still, lows will range from the teens in the Poconos and NW NJ, to the upper 20s for portions of Delmarva.

&&

.LONG TERM /THURSDAY THROUGH TUESDAY/...

Summary...Active late week pattern along with much colder air building in. Some accumulating snow expected for at least portions of our area Thursday night and Friday morning, then potentially during Saturday.

The synoptic pattern is comprised of a split flow at least initially with several pieces of energy moving through. The main time frames of concern are Thursday night and Friday morning, then the first half of the weekend. Given the split flow setup, timing is more important as energy from the northern and southern streams can result in vastly different outcomes. This appears to be the case especially with the weekend potential. The Thursday night and Friday morning event looks to be elongated energy, however enough lift into the deepening cold air associated with weak surface cyclogenesis should enhance the moisture to the northwest for a time. The

challenge is in the details with both of these systems. We used a model/continuity blend Thursday through Friday night, then blended in the 00z WPC Guidance thereafter. Some adjustments were then made following additional collaboration with our neighboring offices.

For Thursday and Friday...A mid level feature sliding across the Ohio Valley Thursday will initiate surface low development near the North Carolina coast. As the mid level feature tracks eastward, moisture may initially get rung out by the Appalachians. However, the model guidance generally agrees with an area of frontogenetic forcing sliding across much of our area which then strengthens some toward the coast as the surface low gets going. While the surface low is forecast to track offshore and be on the weaker side, there looks to be enough connection to toss more moisture northwestward into the lift area. This is expected to develop a swath of light accumulating snow, in the 1-3 inch range with the highest amounts toward the coast. Some guidance has come in a little warmer, although this is mostly in the lowest layers closest to the surface.

Snow should develop from west to east Thursday evening with much of it falling between about 06-12z Friday. This will have an impact on the Friday morning commute as temperatures will support accumulations and slippery conditions on untreated surfaces. We increased PoPs into the likely and categorical range from the I-95 corridor on south and east where there is good model support of measurable precipitation. The PoPs then taper off to the north and west, however even here there could be an area of a coating to an inch. The farther north one goes, drier air may limit any snowfall. Otherwise, lots of clouds should dominate this period along with colder conditions.

For Saturday and Sunday...A significant trough slides across the Great Lakes region Saturday, while within the split flow there is energy moving across the southern states. The latter will be tracking along a baroclinic zone with low pressure moving off the Southeast U.S. coast early Saturday. Given the split flow the model guidance has shown varying solutions, and the key appears to be the timing of the two main pieces of energy. If the southern system can stay ahead of the northern one, more of a turn northward would occur. This would pull the precipitation shield more north and west, like the 00z ECMWF shows. If the southern feature is weaker, then the surface low shifts more offshore and the precipitation shield is not as far north and west. Taking a look at the 500 MB pattern, this system has a chance, with even the more offshore GFS showing potential to back closer to the coast if the southern short wave can sharpen a bit. We will still run with some low chance PoPs closer to the coast on Saturday given at least some potential for a period of snow. This remains a low confidence forecast given the pieces/flow involved, however there is the potential for a snow shield to overspread at least our southern and eastern areas for a time Saturday.

Otherwise, rather cold conditions over the weekend with increasing wind especially later Saturday and Sunday as low pressure deepens as it pulls northeastward and away from our area. Wind chills will be lowering to the teens and single digits, with even below zero

readings forecast Sunday night in the Poconos.

For Monday and Tuesday...The center of very cold high pressure moves across our area Monday before shifting offshore Tuesday. This along with low pressure organizing in the Central Plains will set the stage for warm air advection, resulting in the airmass moderating Tuesday. As the warm air advection overspreads our area, perhaps some overrunning precipitation occurs especially Tuesday night as a warm front arrives. This timing will probably change though, therefore stayed closer to the 00z WPC Guidance.

&&

.AVIATION /12Z WEDNESDAY THROUGH SUNDAY/...

The following discussion is for KPHL, KPNE, KTTN, KABE, KRDG, KILG, KMIV, KACY and surrounding areas.

Ceilings are expected to be variable between LIFR and MVFR through the next few hours, but expect a trend towards improving conditions especially by 15Z. VFR conditions are expected with the cold front which should be moving through the TAF sites between 15 and 18Z. Once conditions improve to VFR with the front, VFR conditions will continue through the rest of the TAF period.

Also with the front, expect an increase in westerly winds with gusts around 25 kt possible through the remainder of the day and much of the evening. Late tonight, winds should drop off to near 10 kt.

Outlook...

Thursday and Friday...VFR ceilings Thursday will then lower to MVFR or IFR at night and Friday morning, before improving to VFR. A period of snow, mainly light, is expected to develop Thursday night and Friday morning which will reduce the visibility. The lowest conditions should be from ILG to PHL/PNE to TTN on south and east. West-southwest winds 10-15 knots Thursday, diminishing to less than 10 knots at night, then becoming northwest around 10 knots Friday.

Saturday...MVFR/IFR possible with a period of snow, mainly for the MIV and ACY areas. Confidence is low regarding the extent of a snow shield with low pressure offshore. Northerly winds around 10 knots.

Sunday...Mainly VFR. Northwest winds 10-15 knots with gusts to 25 knots.

&&

.MARINE...

SCA conditions, primarily for seas will continue especially on the ocean waters through the morning hours. Winds will increase abruptly behind a cold front expected early this afternoon. Although guidance on the Bay and Delaware coastal waters would suggest gusts around 30kt, am concerned that with the wind direction (west northwest), there will be some funneling down the bay which will enhance the gusts on and at the mouth of the bay. Therefore, have expanded the gale warning to include all of the waters.

Winds should decrease late tonight. As they do so, the gale warning will likely need to be replaced with an SCA.

Outlook...

Thursday and Friday...Small Craft Advisory conditions should be subsiding Thursday as the pressure gradient weakens. Northerly winds increase Friday, however they should remain below advisory criteria as well as the seas.

Saturday and Sunday...Low pressure tracks offshore Saturday resulting in a northeasterly flow increasing. This should result in Small Craft Advisory conditions, however the strength of the winds and subsequent wave heights will depend on the intensity and track of the surface low. As the storm lifts to our northeast Sunday, there is a chance for a period of low-end northwesterly gale force gusts later Sunday.

&&

.PHI WATCHES/WARNINGS/ADVISORIES...

PA...None.

NJ...None.

DE...None.

MD...None.

MARINE...Gale Warning from 3 PM this afternoon to 3 AM EST Thursday for ANZ450>453.

Gale Warning from 3 PM this afternoon to midnight EST tonight for ANZ430-431-454-455.

&&

\$\$

Synopsis...Gorse

Near Term...Johnson

Short Term...Johnson

Long Term...Gorse

Aviation...Gorse/Johnson

Marine...Gorse/Johnson

8.0 NWS Zone Forecast Product

The NWS Office in Mount Holly, New Jersey, issued the following zone forecast product (ZFP), which included a forecast for the accident site. The latest forecast valid at the accident time was issued at 1233 EST and it indicated mostly sunny skies, breezy conditions with a west wind of 15 to 20 mph and gusts to 30 mph, with temperatures steady near 50° F. The ZFP valid previous to the ZFP valid at the accident time, was issued at 1040 EST. The 1040 EST ZFP indicated mostly sunny skies, breezy conditions with westerly wind gusts up to 30 mph during the afternoon, and temperatures steady in the upper 40s °F:

104

FPUS51 KPHI 041733

ZFPPHI

ZONE FORECAST PRODUCT FOR SE PA...NJ...AND NORTHERN DELMARVA
NATIONAL WEATHER SERVICE MOUNT HOLLY NJ
1230 PM EST WED JAN 4 2017

PAZ071-042100-
PHILADELPHIA-
INCLUDING THE CITY OF...PHILADELPHIA
1230 PM EST WED JAN 4 2017

**.THIS AFTERNOON...MOSTLY SUNNY AND BREEZY. NEAR STEADY
TEMPERATURE AROUND 50. WEST WINDS 15 TO 20 MPH WITH GUSTS UP TO
30 MPH.**

.TONIGHT...MOSTLY CLEAR AND BREEZY. MUCH COLDER WITH LOWS IN THE
MID 20S. WEST WINDS 15 TO 20 MPH.

.THURSDAY...MOSTLY SUNNY IN THE MORNING...THEN BECOMING CLOUDY.
MUCH COOLER WITH HIGHS IN THE MID 30S. WEST WINDS AROUND 10 MPH.

.THURSDAY NIGHT...CLOUDY. SNOW LIKELY...MAINLY AFTER MIDNIGHT.
LIGHT SNOW ACCUMULATION POSSIBLE. COLD WITH LOWS IN THE UPPER
20S. WEST WINDS AROUND 5 MPH. CHANCE OF SNOW 60 PERCENT.

.FRIDAY...CLOUDY WITH A CHANCE OF SNOW IN THE MORNING...THEN
PARTLY SUNNY IN THE AFTERNOON. HIGHS IN THE MID 30S. NORTHWEST
WINDS AROUND 5 MPH. CHANCE OF SNOW 30 PERCENT.

.FRIDAY NIGHT...MOSTLY CLOUDY. COLD WITH LOWS IN THE LOWER 20S.

.SATURDAY...PARTLY SUNNY. COLD WITH HIGHS IN THE UPPER 20S.

.SATURDAY NIGHT...PARTLY CLOUDY. COLD WITH LOWS 15 TO 20.

.SUNDAY...MOSTLY SUNNY AND BRISK. COLD WITH HIGHS IN THE UPPER
20S.

.SUNDAY NIGHT...MOSTLY CLEAR. COLD WITH LOWS 10 TO 15.

.MONDAY...MOSTLY SUNNY. COLD WITH HIGHS IN THE UPPER 20S.

.MONDAY NIGHT...MOSTLY CLOUDY. COLD WITH LOWS AROUND 20.

.TUESDAY...PARTLY SUNNY. NOT AS COOL WITH HIGHS IN THE UPPER 30S.

\$\$

405
FPUS51 KPHI 041540
ZFPPHI

ZONE FORECAST PRODUCT FOR SE PA...NJ...AND NORTHERN DELMARVA
NATIONAL WEATHER SERVICE MOUNT HOLLY NJ
1040 AM EST WED JAN 4 2017

PAZ071-042130-
PHILADELPHIA-
INCLUDING THE CITY OF...PHILADELPHIA
1040 AM EST WED JAN 4 2017

**.REST OF TODAY...MOSTLY SUNNY AND BREEZY. NEAR STEADY TEMPERATURE
IN THE UPPER 40S. WEST WINDS AROUND 10 MPH WITH GUSTS UP TO
20 MPH...INCREASING TO 15 TO 20 MPH WITH GUSTS UP TO 30 MPH THIS
AFTERNOON.**

.TONIGHT...MOSTLY CLEAR AND BREEZY. MUCH COLDER WITH LOWS IN THE
MID 20S. WEST WINDS 15 TO 20 MPH.

.THURSDAY...MOSTLY SUNNY IN THE MORNING...THEN BECOMING CLOUDY.
MUCH COOLER WITH HIGHS IN THE MID 30S. WEST WINDS AROUND 10 MPH.

.THURSDAY NIGHT...CLOUDY. SNOW LIKELY...MAINLY AFTER MIDNIGHT.
LIGHT SNOW ACCUMULATION POSSIBLE. COLD WITH LOWS IN THE UPPER
20S. WEST WINDS AROUND 5 MPH. CHANCE OF SNOW 60 PERCENT.
.FRIDAY...CLOUDY WITH A CHANCE OF SNOW IN THE MORNING...THEN
PARTLY SUNNY IN THE AFTERNOON. HIGHS IN THE MID 30S. NORTHWEST
WINDS AROUND 5 MPH. CHANCE OF SNOW 30 PERCENT.
.FRIDAY NIGHT...MOSTLY CLOUDY. COLD WITH LOWS IN THE LOWER 20S.
.SATURDAY...PARTLY SUNNY. COLD WITH HIGHS IN THE UPPER 20S.
.SATURDAY NIGHT...PARTLY CLOUDY. COLD WITH LOWS 15 TO 20.
.SUNDAY...MOSTLY SUNNY AND BRISK. COLD WITH HIGHS IN THE UPPER
20S.
.SUNDAY NIGHT...MOSTLY CLEAR. COLD WITH LOWS 10 TO 15.
.MONDAY...MOSTLY SUNNY. COLD WITH HIGHS IN THE UPPER 20S.
.MONDAY NIGHT...MOSTLY CLOUDY. COLD WITH LOWS AROUND 20.
.TUESDAY...PARTLY SUNNY. NOT AS COOL WITH HIGHS IN THE UPPER 30S.

\$\$

9.0 Solar Angle Data

The solar angle was calculated for the accident site at the accident time (figure 13). The sun location was indicated as having an azimuth of 190.6° and an elevation of 26.71° (figure 13, yellow line). Sunrise and sunset locations are shown on figure 13 with green and red lines, respectively.

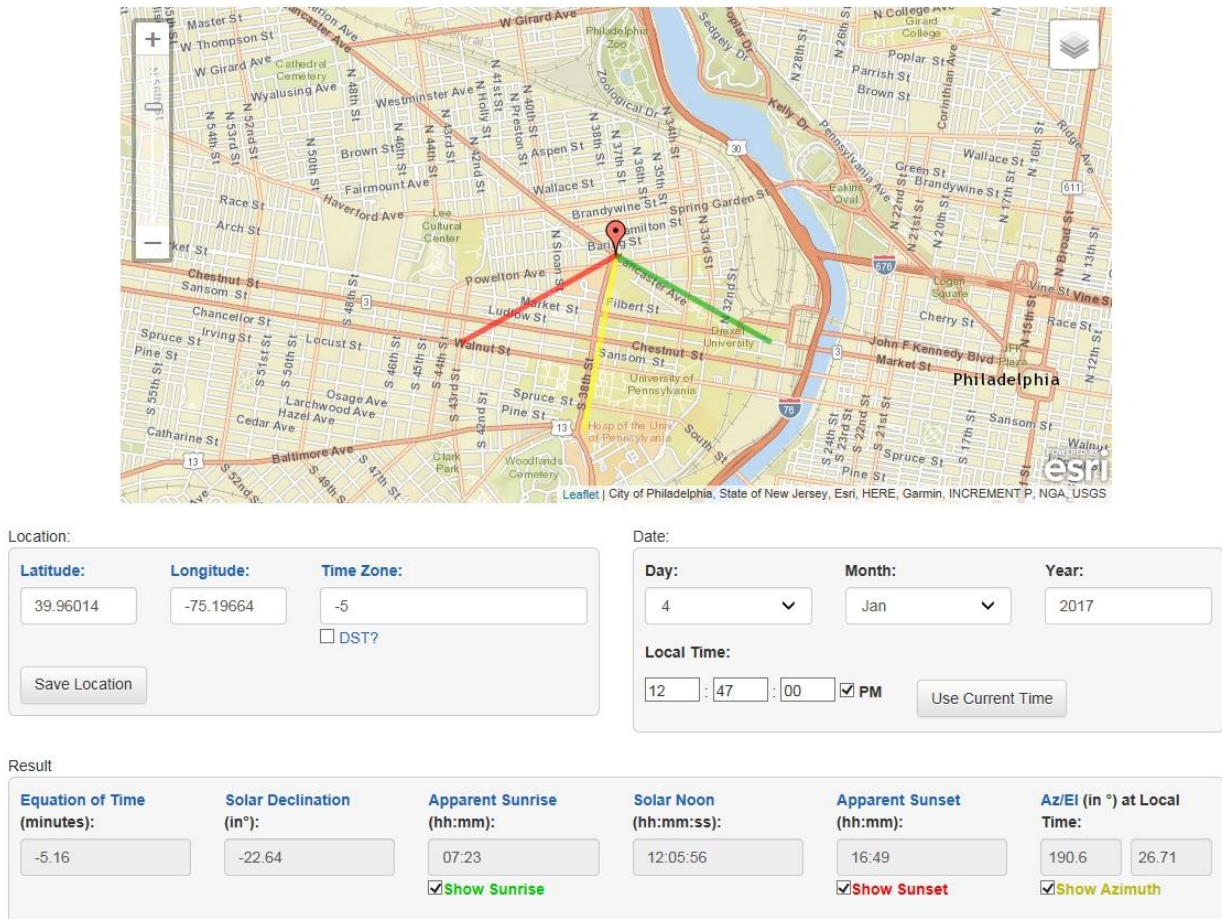


Figure 13 – Sun angle location information around the accident time

10.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on January 4, 2017, indicated the following:

SUN	
Begin civil twilight	0652 EST
Sunrise	0723 EST
Sun transit	1206 EST
Sunset	1649 EST
End civil twilight	1719 EST

E. LIST OF ATTACHMENTS

None.

Submitted by:

Paul Suffern
Senior Meteorologist

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