



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

June 11, 2019

Factual Report

METEOROLOGY

ERA19LA072

Table Of Contents

A. ACCIDENT	4
B. METEOROLOGIST	4
C. DETAILS OF THE INVESTIGATION	4
D. WEATHER INFORMATION	4
1.0 Synoptic Situation	4
1.1 Surface Analysis Chart	5
1.2 Upper Air Charts	6
2.0 SPC Products	10
3.0 Surface Observations	15
4.0 Upper Air Data	18
5.0 Satellite Data	20
6.0 Regional Radar Imagery Information	21
7.0 Radar Imagery Information	22
7.1 Volume Scan Strategy	22
7.2 Beam Height Calculation	23
7.3 Reflectivity	24
7.4 Base Reflectivity and Lightning Data	25
7.5 Dual-Pol Products	27
7.6 Dual-Pol Imagery	28
8.0 Pilot Reports	33
9.0 SIGMET	35
10.0 CWSU Products	35
11.0 AIRMETs	36
12.0 Graphical Forecasts for Aviation	38
13.0 Terminal Aerodrome Forecast	38
14.0 NWS Area Forecast Discussion	39
15.0 NWS Special Marine Warning	42
16.0 Winds and Temperature Aloft Forecast	44
17.0 Pilot Weather Briefing	44
18.0 CWSU Weather Briefing for ATC	44
19.0 Icing Potential	45
20.0 XM Weather images	52
21.0 Advisory Circular 91-74B	55

22.0	Astronomical Data	55
E.	LIST OF ATTACHMENTS	55

A. ACCIDENT

Location: Near Mayport, Florida
Date: December 20, 2018
Time: 0904 eastern standard time
1404 Coordinated Universal Time (UTC)
Aircraft: Piper PA-46-350P, Registration: N307JM

B. METEOROLOGIST

Paul Suffern
Senior Meteorologist
Operational Factors Division (AS-30)
National Transportation Safety Board

C. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's (NTSB) Meteorologist did not travel for this investigation and gathered the weather data for this investigation from official National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sources including the National Centers for Environmental Information (NCEI). All times are eastern standard time (EST) on December 20, 2018, 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 last air traffic control (ATC) target point was at 0904:40 EST, at latitude 30.4007° N, longitude 81.3844° W, with an approximate elevation of 1,700 feet (ft).

D. WEATHER INFORMATION

1.0 Synoptic Situation

The synoptic or large scale migratory weather systems influencing the area were documented using standard NWS charts issued by the National Center for Environmental Prediction and the Weather Prediction Center, located in College Park, Maryland. These are the base products used in describing synoptic weather features and in the creation of forecasts and warnings for the NWS. Reference to these charts can be found in the joint NWS and Federal Aviation Administration (FAA) Advisory Circular "Aviation Weather Services", AC 00-45H.¹

¹

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

1.1 Surface Analysis Chart

The southeast section of the NWS Surface Analysis Chart for 1000 EST is provided as figure 1 with the approximate location of the last ATC target point marked within the red circle. The chart identified surface low pressure centers located over central and southern Alabama with surface pressures of 1002- and 1001-hectopascals (hPa), respectively. A warm front stretched from southern Alabama eastward through southern Georgia (north of the accident site) and into eastern North Carolina. A cold front stretched southward from southern Alabama into the central Gulf of Mexico. Ahead of the cold front, a north-to-south oriented trough² was located in the eastern Gulf of Mexico. The accident site was located in the warm air sector of the front.

The station models around the accident site depicted air temperatures in the mid to upper 60's degrees Fahrenheit (°F), dew point temperatures in the mid 60's °F with temperature-dew point spreads of 1° F or less, with south to southeast winds of 10 to 20 knots, overcast sky cover, with light continuous rain.

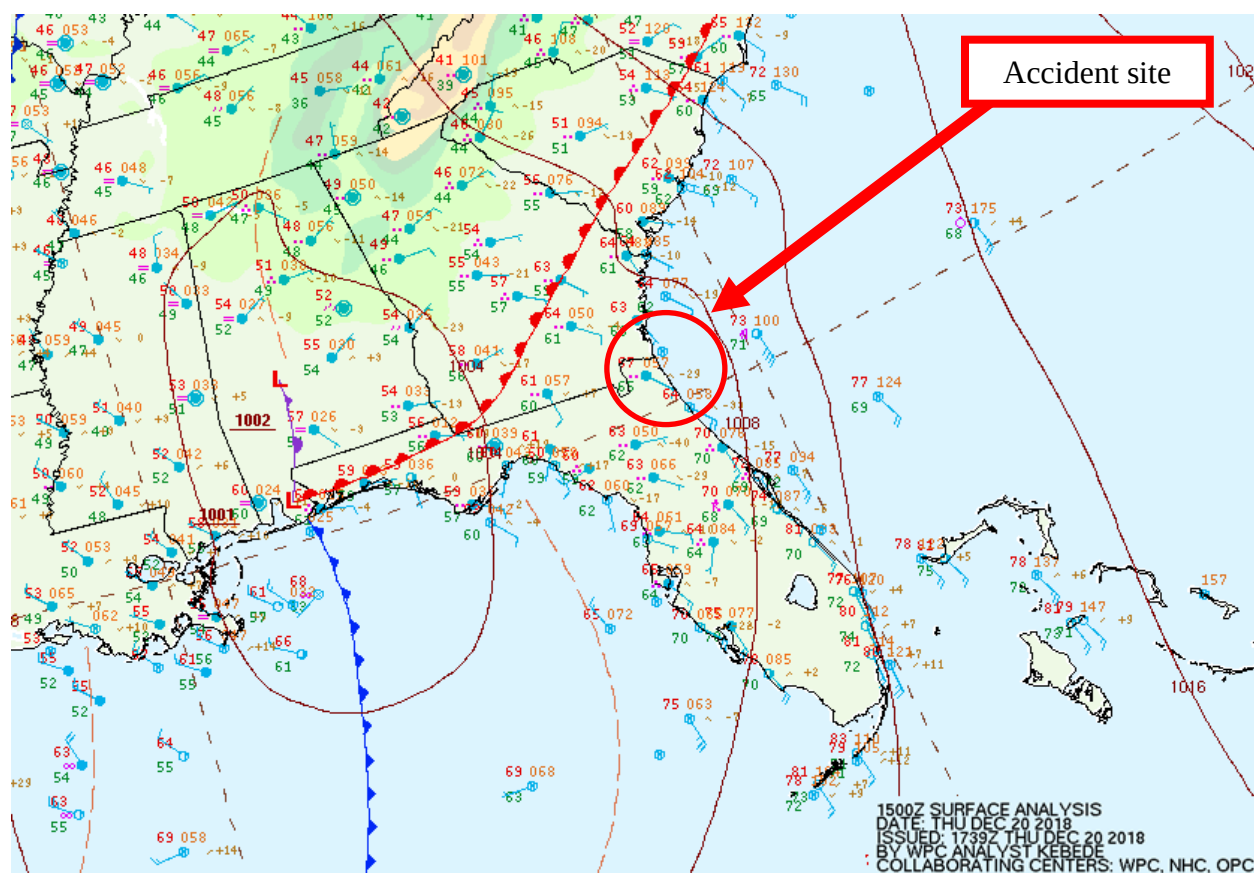


Figure 1 – NWS Surface Analysis Chart for 1000 EST

² 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 0700 EST at 925-, 850-, 700-, 500-, and 300-hPa are presented in figures 2 through 6. There was a low-level trough extending southward into the Gulf of Mexico located southwest of the accident site (figures 2 and 3) at 925- and 850-hPa. Troughs can act as lifting mechanisms to help produce clouds and precipitation if sufficient moisture is present. There was also a mid-level trough located southwest of the accident site in the eastern Gulf of Mexico at 700- and 500-hPa (figures 4 and 5). There was a southeast wind of 30 knots at 925-hPa above the accident site with the wind becoming southerly by 700-hPa (figure 4) at 45 knots. By 300-hPa, the wind above the accident site was from the southwest and the wind speed increased 80 knots (figure 6).

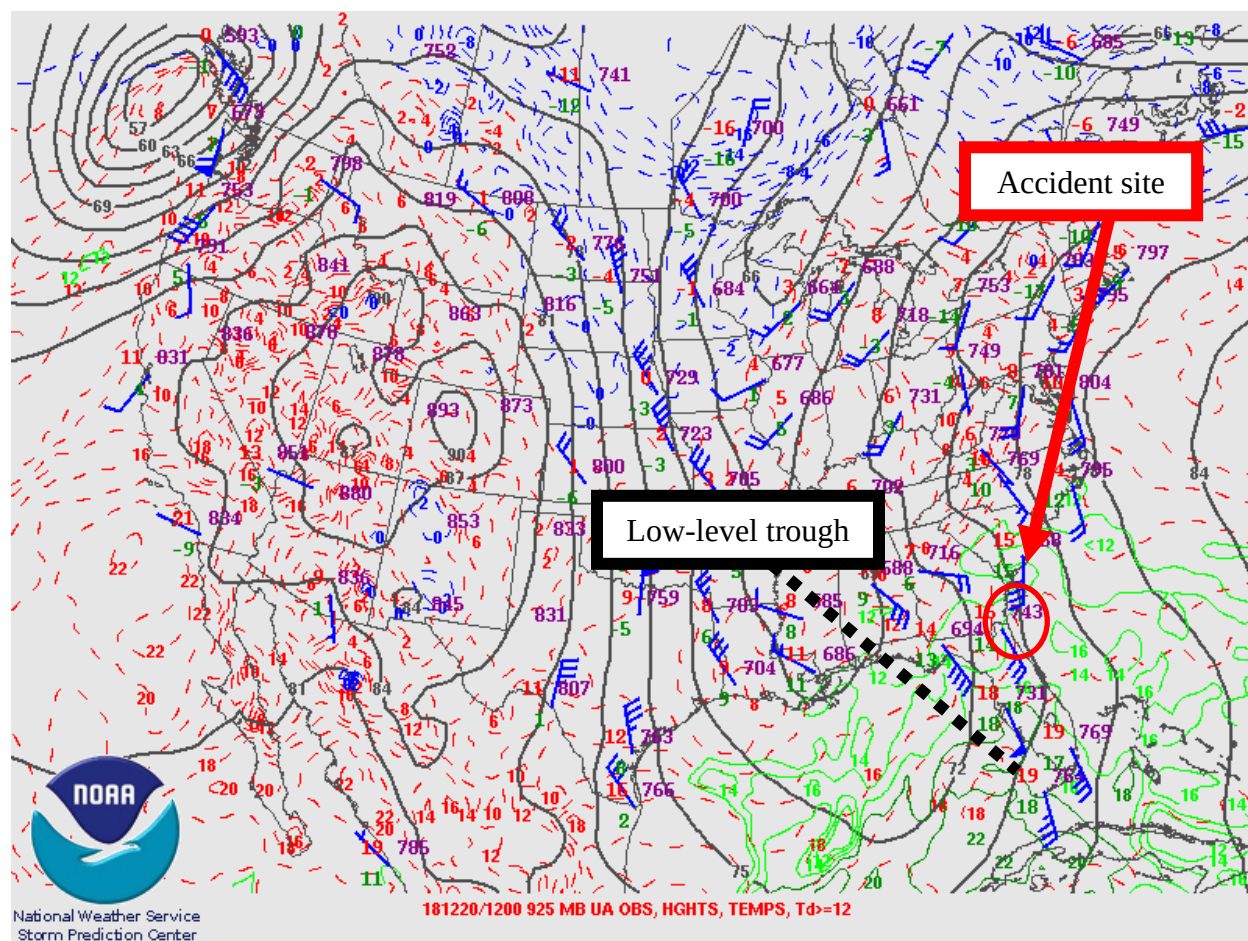


Figure 2 – 925-hPa Constant Pressure Chart for 0700 EST

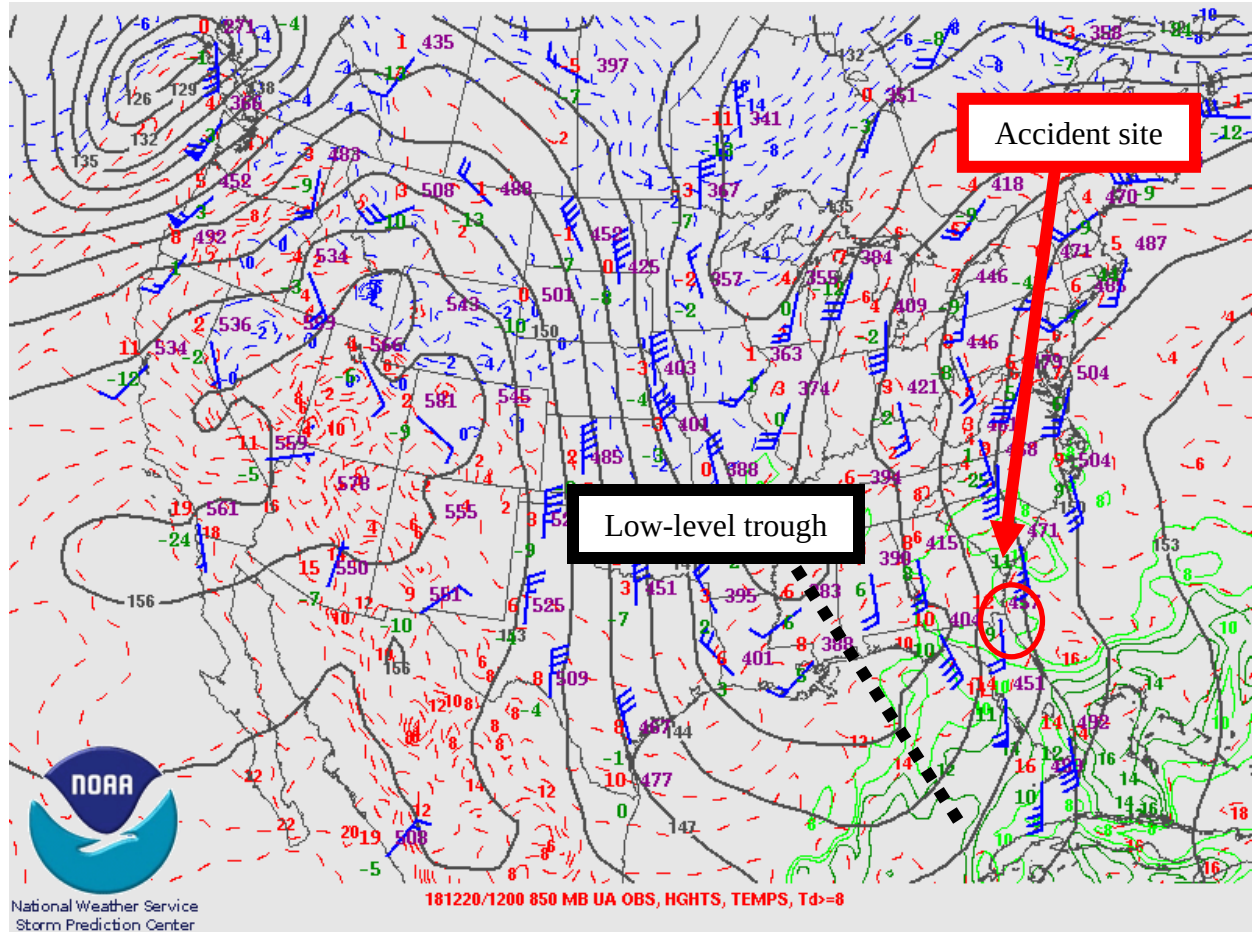


Figure 3 – 850-hPa Constant Pressure Chart for 0700 EST

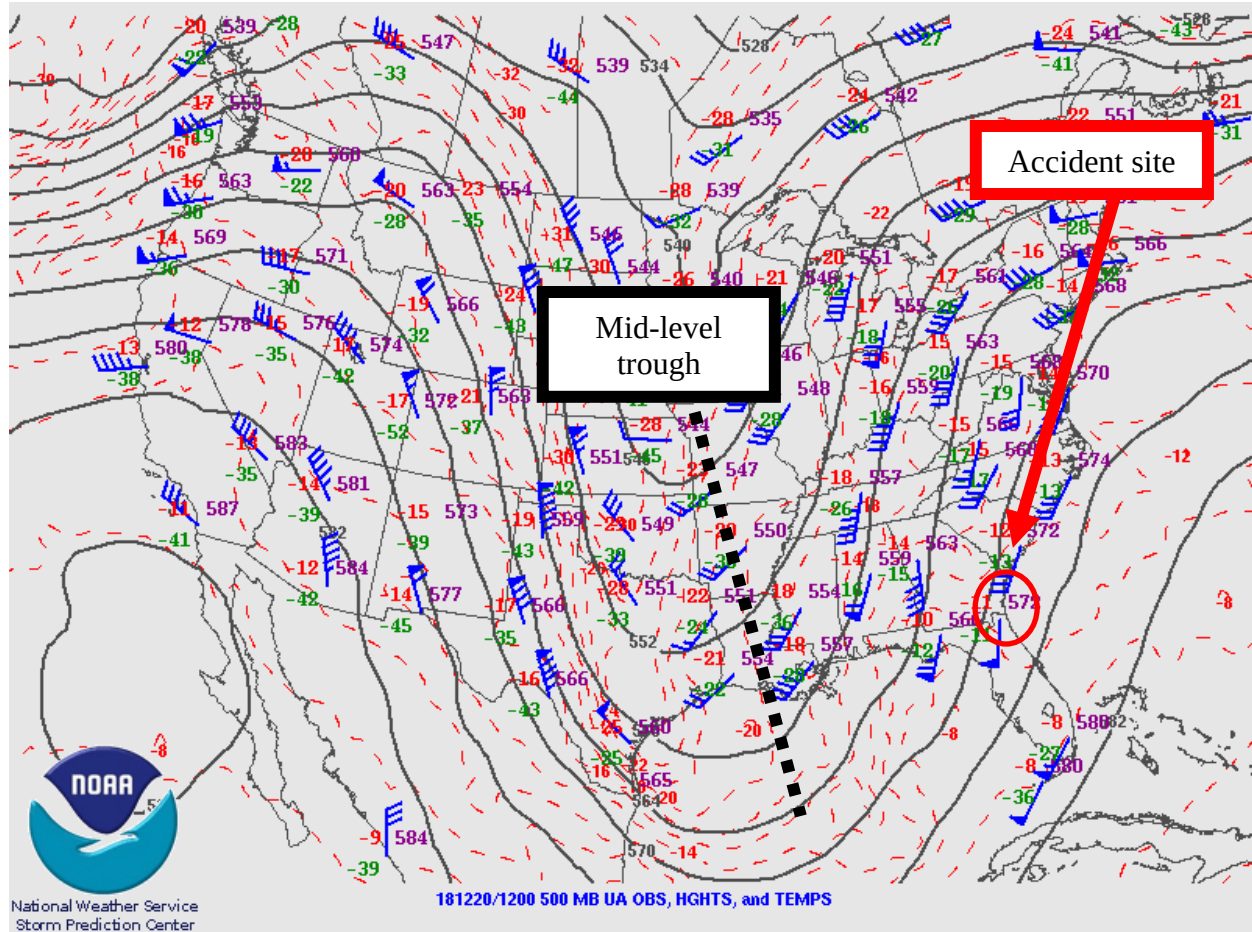


Figure 5 – 500-hPa Constant Pressure Chart for 0700 EST

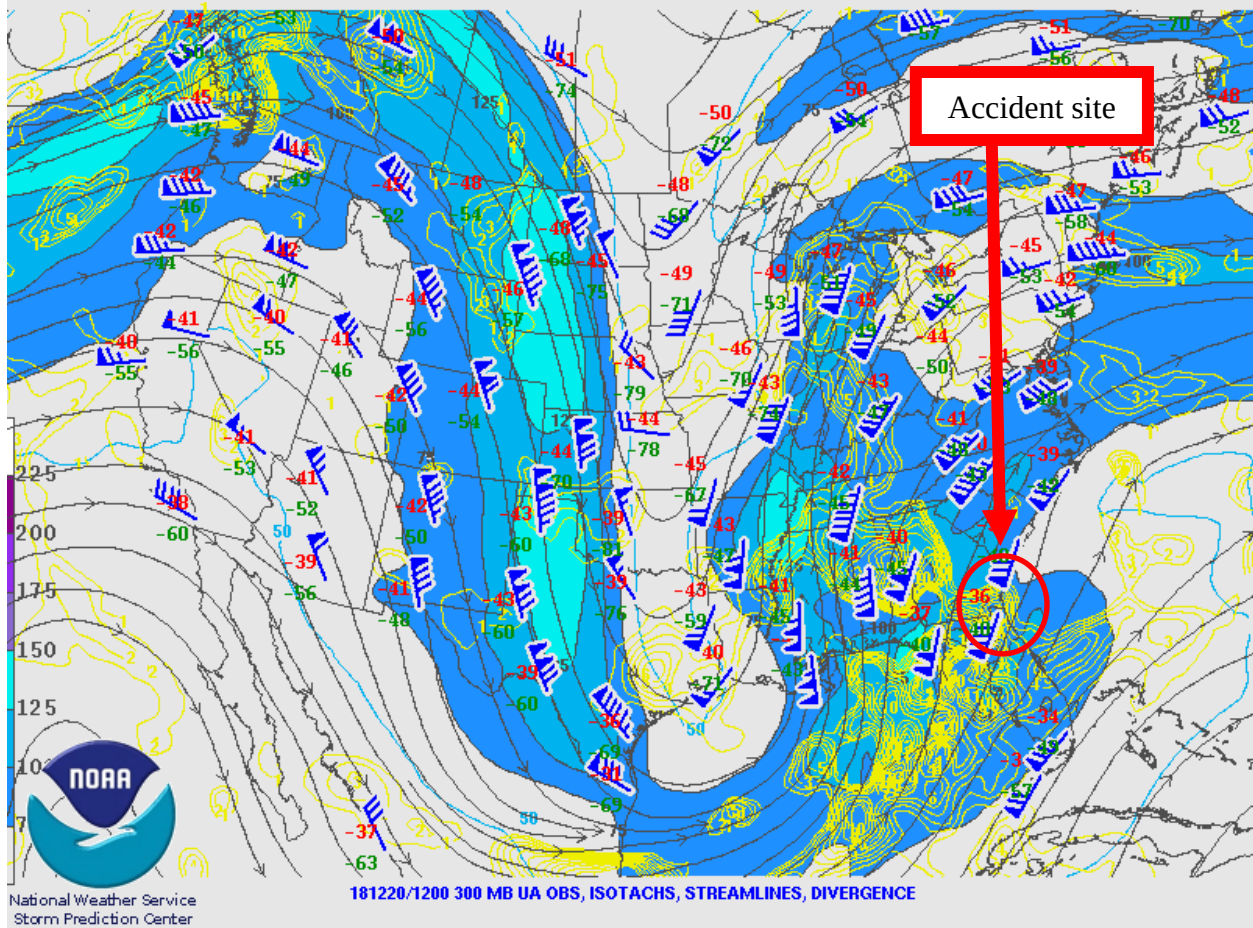


Figure 6 – 300-hPa Constant Pressure Chart for 0700 EST

2.0 SPC Products

SPC issued the following Day 1 Convective Outlook at 0758 EST (figure 7) with areas of general thunderstorms forecast for the accident site. SPC defines the “TSTM” area as an area that encloses where a 10% or higher probability of thunderstorms is forecast during the valid period. The accident site was also located just north of enhanced areas where there was potential for tornadoes and damaging surface wind gusts with the thunderstorm activity (figures 8 and 9). The SPC Day 1 Convective Outlook text follows figure 9:

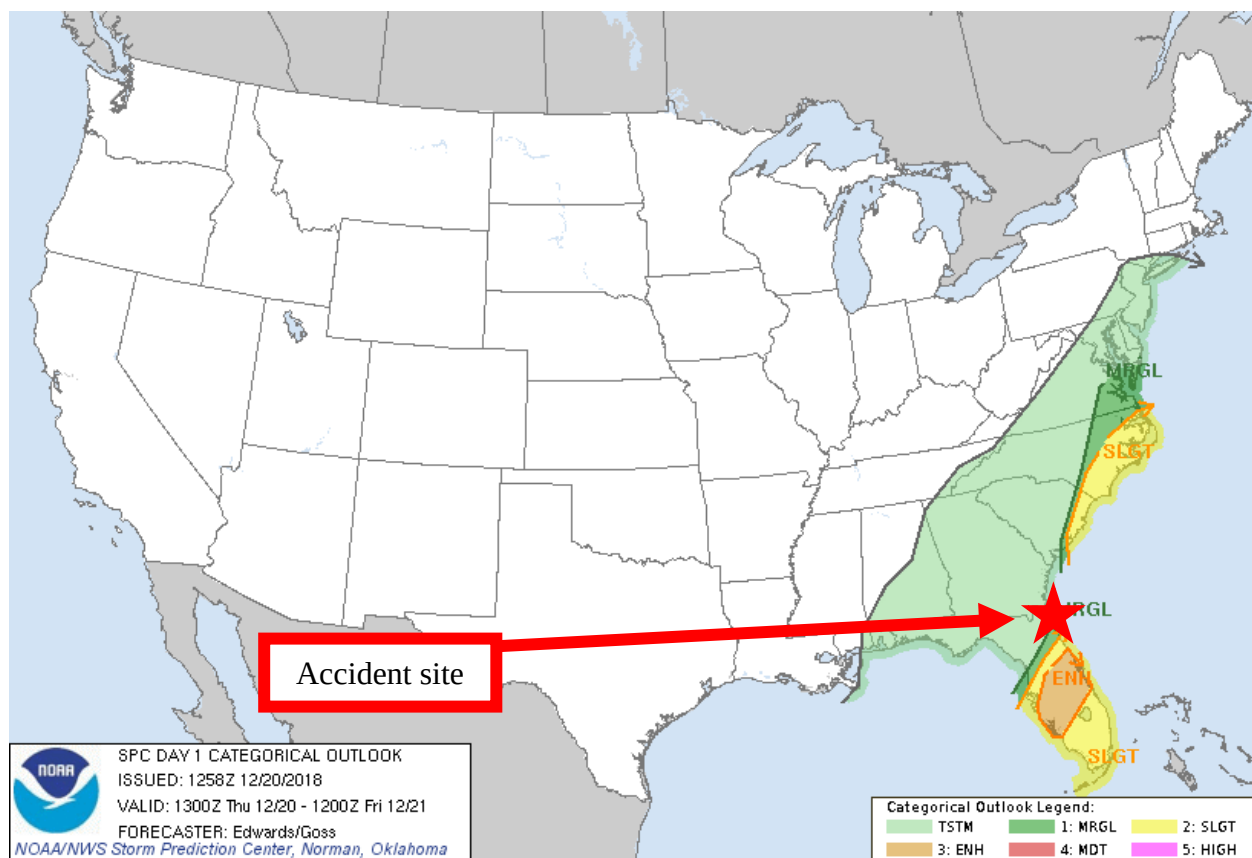


Figure 7 – SPC day 1 Convective Outlook valid at the time of the accident

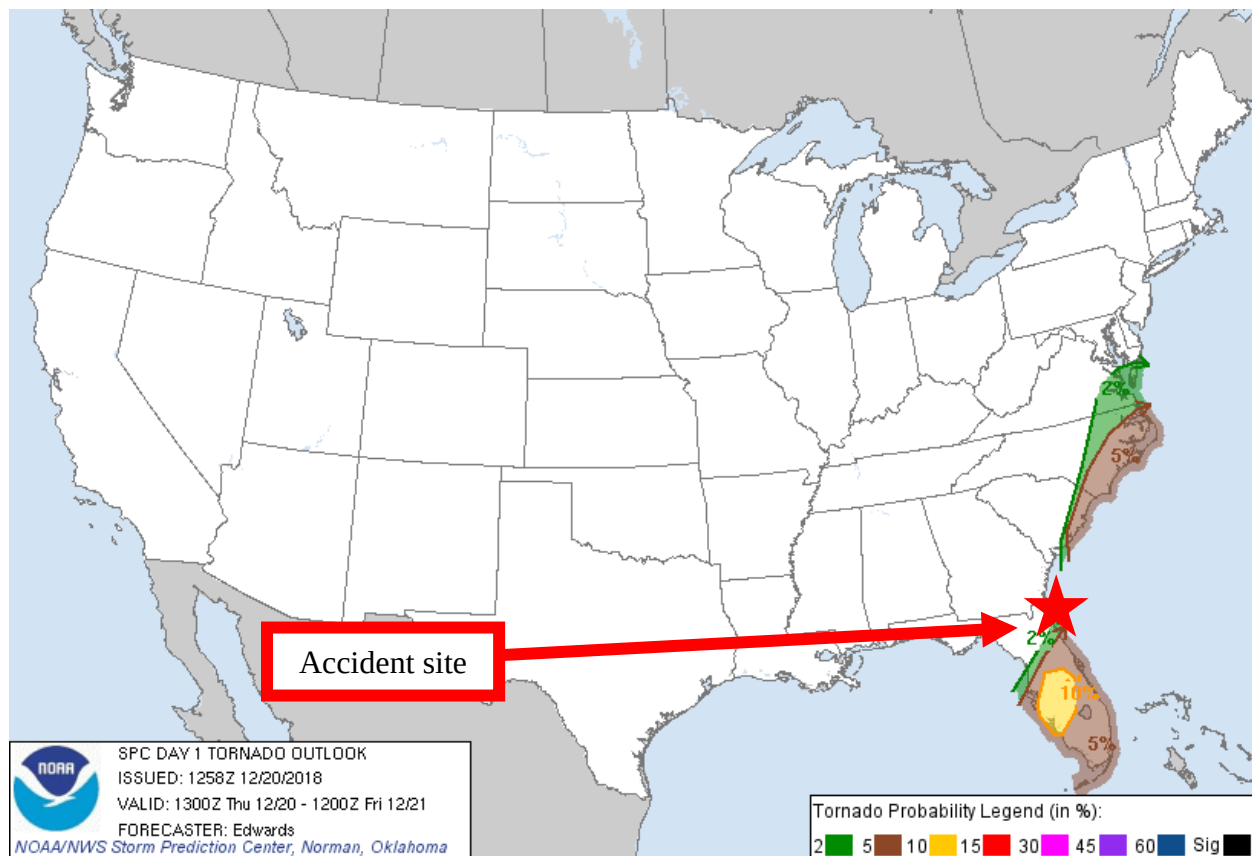


Figure 8 – SPC day 1 Tornado Outlook valid at the time of the accident

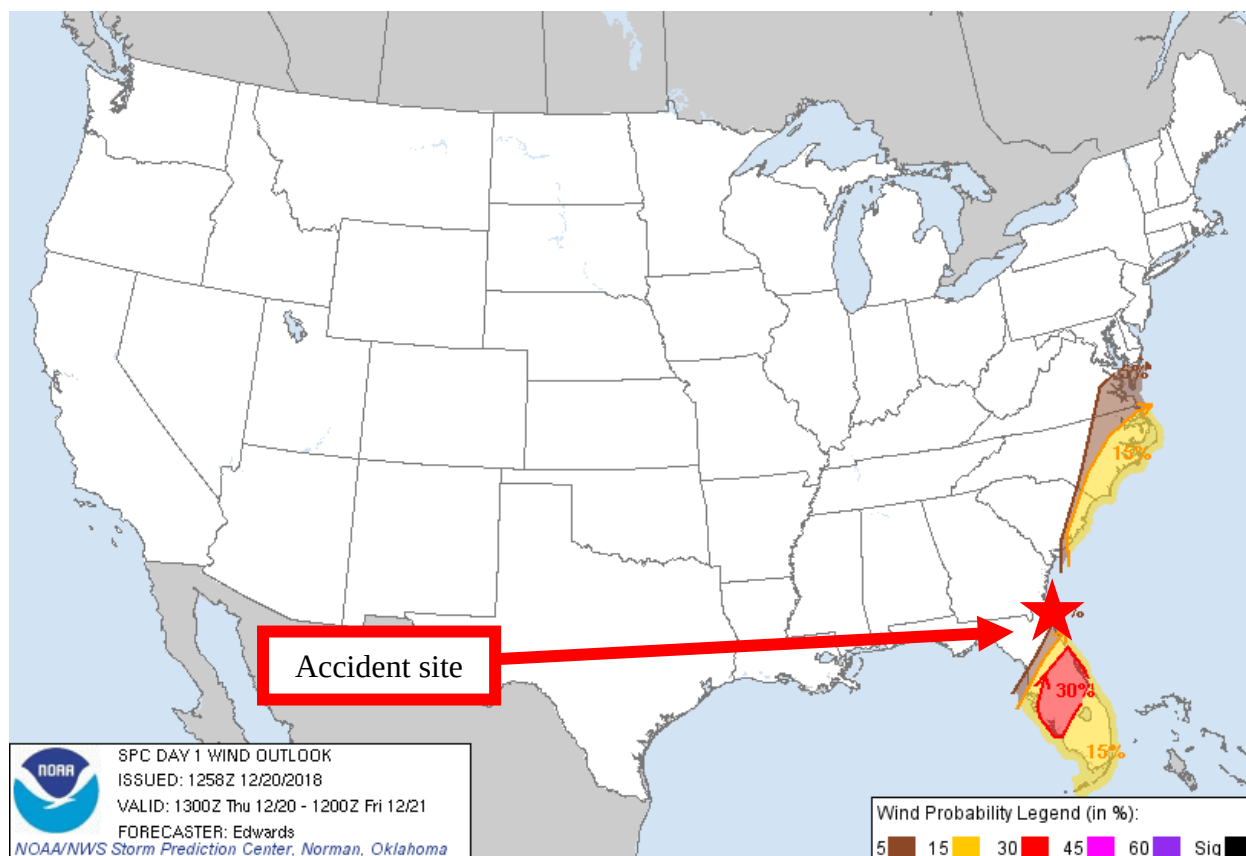


Figure 9 – SPC day 1 Wind Outlook valid at the time of the accident

SPC AC 201258

Day 1 Convective Outlook
 NWS Storm Prediction Center Norman OK
 0658 AM CST Thu Dec 20 2018

Valid 201300Z - 211200Z

...THERE IS AN ENHANCED RISK OF SEVERE THUNDERSTORMS OVER PARTS OF CENTRAL TO SOUTHWEST FLORIDA...

...THERE IS A SLIGHT RISK OF SEVERE THUNDERSTORMS SURROUNDING THE FLORIDA ENHANCED RISK...AS WELL AS OVER PARTS OF THE EASTERN CAROLINAS...

...SUMMARY...

Damaging thunderstorm winds and tornadoes are possible across much of the Florida Peninsula today, and in eastern portions of the Carolinas late afternoon into tonight.

...Synopsis...

In mid/upper levels, a series of vorticity maxima will dig into an already high-amplitude/full-latitude synoptic trough, currently located from northwest ON across MN, IA, eastern OK, east TX, and the western Gulf down across the Bay of Campeche. By the end of the period, the trough should be located from the upper Great Lakes

across AL to the Yucatan Peninsula vicinity, with anomalously low heights and intense height gradients at low latitudes. The net result will be a slight broadening and intensification of the cyclonic flow field across the Gulf. The 250-mb jet should increase from the 110-120 kt range over the eastern Gulf and FL at 00Z to 130-150 kt from northern FL to the eastern Carolinas by 12Z.

At the surface, 11Z analysis showed the main frontal-wave low over the MOB area with a secondary/weaker low near TLH, amidst a broader, diffuse area of low pressure covering much of MS/AL southward over the Gulf. A cold front was drawn from the MOB-area low southward across the central gulf then southwestward to the southwestern Gulf.

Two warm fronts were evident:

1. A synoptic boundary in cooler air through those lows and eastward across extreme northern FL, and
2. A maritime/tropical boundary very near the southwest FL coast and across the southern Everglades, arching northward along or just east of the southeastern FL Atlantic coast. The two warm-frontal zones are diffusely merging offshore from SC.

The low-pressure area is forecast to intensify and elongate along the cold front, while moving north-northeastward over the southern and central Appalachians. By 00Z the cold front should extend from eastern AL across the central/eastern FL Panhandle and northeastern Gulf. The cold front, rendered somewhat nebulous by antecedent convective processes, should cross most of FL through the overnight hours. Meanwhile the marine/warm front will shift northward through the preconvective sector over the peninsula, and should move slightly northeastward/inland over the eastern Carolinas on the northern rim of a more incompletely marine-modified boundary layer than over FL.

...FL...

Scattered to numerous thunderstorms are expected to move northeastward across the outlook area through this evening in two primary bands:

1. Morning activity now over the TBW/SRQ areas and extending southwestward across the Gulf. A marginal tornado threat exists in the next hour or two with this activity as it moves inland.
2. A longer band in both spatial length and timespan, expected to consolidate over the Gulf and west-central FL behind the morning convection and initially ahead of the front. This evening and overnight, the front should catch up and cause some eastward acceleration of the resulting QLCS as a whole across the remainder of eastern/southern FL.

Following the morning activity, the main band should move into an increasingly high-thetae air mass over southwest, east-central and southeast FL. Meanwhile, over central FL, this QLCS will have more limited recovery time with weaker buoyancy. A moist, southerly Caribbean return-flow fetch will serve both to destabilize the boundary layer and keep winds backed enough to maintain favorably large low-level hodographs. This is in notable contrast to many cool-season frontal-passage convective scenarios in FL, where surface flow substantially veers and reduces SRH/convergence. Instead, the general mass response to the low-latitude mid/upper

processes will maintain a favorable CAPE/shear parameter spaces ahead of the line for bow/LEWP formations, embedded supercells and QLCS mesovortices, with associated tornadic and nontornadic wind potential.

...Eastern Carolinas to southeastern VA this evening...

A prefrontal band of strong-severe thunderstorms -- at least loosely manifesting the northern extension of the FL activity -- is expected to sweep north-northeastward across the Atlantic off GA and parts of SC, crossing coastal northeastern SC and eastern NC this evening into tonight. Damaging winds are the main concern, and a tornado threat also exists.

Though the most-unstable boundary layer will remain over the Atlantic, partially modified marine air will spread somewhat inland across this region, amidst modest but sufficient lapse rates to support roughly 200-600 J/kg MLCAPE. Though instability will be marginal, and diminishing with northward extent across eastern NC into VA, sufficiently intense deep-layer winds, and both flow and shear in the lowest few km above the surface, will support a 15%/slight-risk-level wind-damage threat wherever unstable surface-based parcels are present, and a marginal threat farther north into very shallow layers of weak near-surface static stability.

..Edwards/Goss.. 12/20/2018

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

3.0 Surface Observations

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

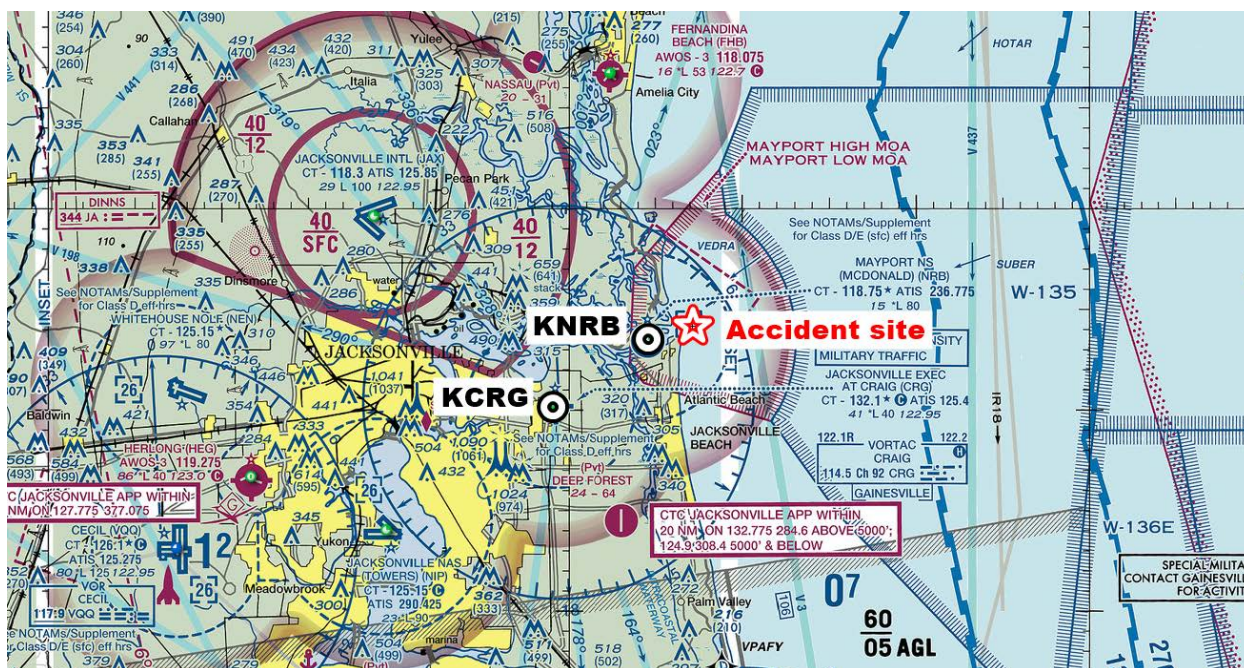


Figure 10 – Sectional map of the accident area with the location of the accident site and surface observation sites

Mayport Naval Station (KNRB) had the closest official weather station to the accident site and was located 1 mile northwest of Mayport, Florida. KNRB had an official weather observer documenting the weather conditions. KNRB was located 2 miles west-southwest of the last ATC target point, at an elevation of 15 ft, and had a 6° westerly magnetic variation³ (figure 10). The following observations were taken and disseminated during the times surrounding the accident:⁴

- [0252 EST] METAR KNRB 200752Z AUTO 15007KT 10SM FEW070 BKN110 17/16
A2983 RMK AO2 RAE38 PRESFR SLP100 P0001 T01670156 \$=
- [0352 EST] METAR KNRB 200852Z AUTO 18010KT 10SM BKN120 18/16 A2983 RMK
AO2 SLP101 60003 T01780156 55021 \$=
- [0452 EST] METAR KNRB 200952Z AUTO 17008KT 10SM -RA BKN060 OVC110 18/16
A2983 RMK AO2 RAB00 SLP099 P0001 T01780156 \$=
- [0509 EST] SPECI KNRB 201009Z 18007KT 7SM -RA OVC050 18/16 A2983 RMK
AO2 P0001 T01780161 \$=

³ Magnetic variation – The angle (at a particular location) between magnetic north and true north. Latest measurement taken from <https://skyvector.com/>

⁴ The bold sections in this NWS product and the rest of the 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 this section next to the METARs are provided for quick reference between UTC and local times around the accident time.

[0552 EST] METAR KNRB 201052Z 19009KT 7SM -RA OVC050 18/17 A2983 RMK AO2 SLP099 P0004 T01830167 \$=

[0652 EST] METAR KNRB 201152Z 16007KT 5SM -RA BR BKN040 OVC100 18/17 A2979 RMK AO2 SLP088 P0005 60013 70015 T01830172 10183 20150 58013 \$=

[0752 EST] METAR KNRB 201252Z 18010KT 5SM RA BR SCT008 BKN040 OVC100 19/18 A2980 RMK AO2 SLP090 P0007 T01890178 \$=

[0852 EST] METAR KNRB 201352Z 14009KT 6SM -RA BR SCT040 OVC100 19/18 A2976 RMK AO2 SLP077 T2 SET P0004 T01890178=

ACCIDENT TIME 0904 EST

[0930 EST] SPECI KNRB 201430Z 14013KT 3SM RA BR SCT006 BKN020 OVC045 18/18 A2975 RMK AO2 T2 SET P0007 T01830178=

[0952 EST] METAR KNRB 201452Z 13014KT 4SM -RA BR SCT006 BKN020 OVC045 18/18 A2972 RMK AO2 SLP064 T2 SET P0009 60020 T01830178 58024=

[1011 EST] SPECI KNRB 201511Z 12012KT 4SM -RA BR BKN005 OVC020 19/18 A2969 RMK AO2 PRESFR T2 SET P0000 T01890183=

[1024 EST] SPECI KNRB 201524Z 12013G20KT 5SM -RA BR SCT005 SCT015 OVC040 18/18 A2966 RMK AO2 PRESFR T2 SET P0001 T01830183=

KNRB weather at 0752 EST, wind from 180° at 10 knots, 5 miles visibility, moderate rain, mist, scattered clouds at 800 ft above ground level (agl), broken ceiling at 4,000 ft agl, overcast skies at 10,000 ft agl, temperature of 19° Celsius (C), dew point temperature of 18° C, and an altimeter setting of 29.80 inches of mercury. Remarks: automated station with a precipitation discriminator, sea level pressure 1009.0 hPa, 0.07 inches of precipitation since 0652 EST, temperature 18.9° C, dew point temperature 17.8° C, maintenance is needed on the system.

KNRB weather at 0852 EST, wind from 140° at 9 knots, 6 miles visibility, light rain, mist, scattered clouds at 4,000 ft agl, overcast ceiling at 10,000 ft agl, temperature of 19° C, dew point temperature of 18° C, and an altimeter setting of 29.76 inches of mercury. Remarks: automated station with a precipitation discriminator, sea level pressure 1007.7 hPa, thunderstorm conditions are forecasted within 25 miles of KNRB, 0.04 inches of precipitation since 0752 EST, temperature 18.9° C, dew point temperature 17.8° C.

KNRB weather at 0930 EST, wind from 140° at 13 knots, 3 miles visibility, moderate rain, mist, scattered clouds at 600 ft agl, broken ceiling at 2,000 ft agl, overcast skies at 4,500 ft agl, temperature of 18° C, dew point temperature of 18° C, and an altimeter setting of 29.75 inches of mercury. Remarks: automated station with a precipitation discriminator, thunderstorm conditions are forecasted within 25 miles of KNRB, 0.07 inches of precipitation since 0852 EST, temperature 18.3° C, dew point temperature 17.8° C.

KNRB weather at 0952 EST, wind from 130° at 14 knots, 4 miles visibility, light rain, mist, scattered clouds at 600 ft agl, broken ceiling at 2,000 ft agl, overcast skies at 4,500 ft agl, temperature of 18° C, dew point temperature of 18° C, and an altimeter setting of 29.72 inches of mercury. Remarks: automated station with a precipitation discriminator, sea level pressure 1006.4 hPa, thunderstorm conditions are forecasted within 25 miles of KNRB, 0.09 inches of precipitation since 0852 EST, 6-hourly precipitation of 0.20 inches, temperature 18.3° C, dew point temperature 17.8° C, 3-hourly pressure drop of 2.4 hPa.

The observations from KNRB surrounding the accident time indicated MVFR⁵ conditions with moderate to light rain, with thunderstorms forecast within 25 miles expected near the station.

4.0 Upper Air Data

The closest official upper air sounding to the accident site was from Jacksonville, Florida, KJAX, located 17 miles west-northwest of the last ATC target point, with a site number 72206, with an elevation of 30 ft. The 0700 EST KJAX sounding was plotted on a standard Skew-T Log P diagram⁶ with the derived stability parameters included in figure 11 (with data from the surface to 200-hPa, or around 40,000 ft msl.) This data was analyzed using the RAOB⁷ software package. The sounding depicted the lifted condensation level (LCL)⁸ at 239 ft msl (209 ft agl) and the convective condensation level (CCL)⁹ at 2,361 ft msl (2,331 ft agl). The freezing level was at 11,779 ft msl. The precipitable water value was 1.66 inches.

⁵ Marginal Visual Flight Rules – Refers to the general weather conditions pilots can expect at the surface. MVFR criteria means a ceiling 1,000 to 3,000 ft agl and/or 3 to 5 miles visibility.

⁶ 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.

⁷ RAOB – (The complete Rawinsonde Observation program) is an interactive sounding analysis program developed by Environmental Research Services, Matamoras, Pennsylvania.

⁸ LCL - The height at which a parcel of moist air becomes saturated when it is lifted dry adiabatically.

⁹ CCL – The level in the atmosphere to which an air parcel, if heated from below, will rise dry adiabatically, without becoming colder than its environment just before the parcel becomes saturated.

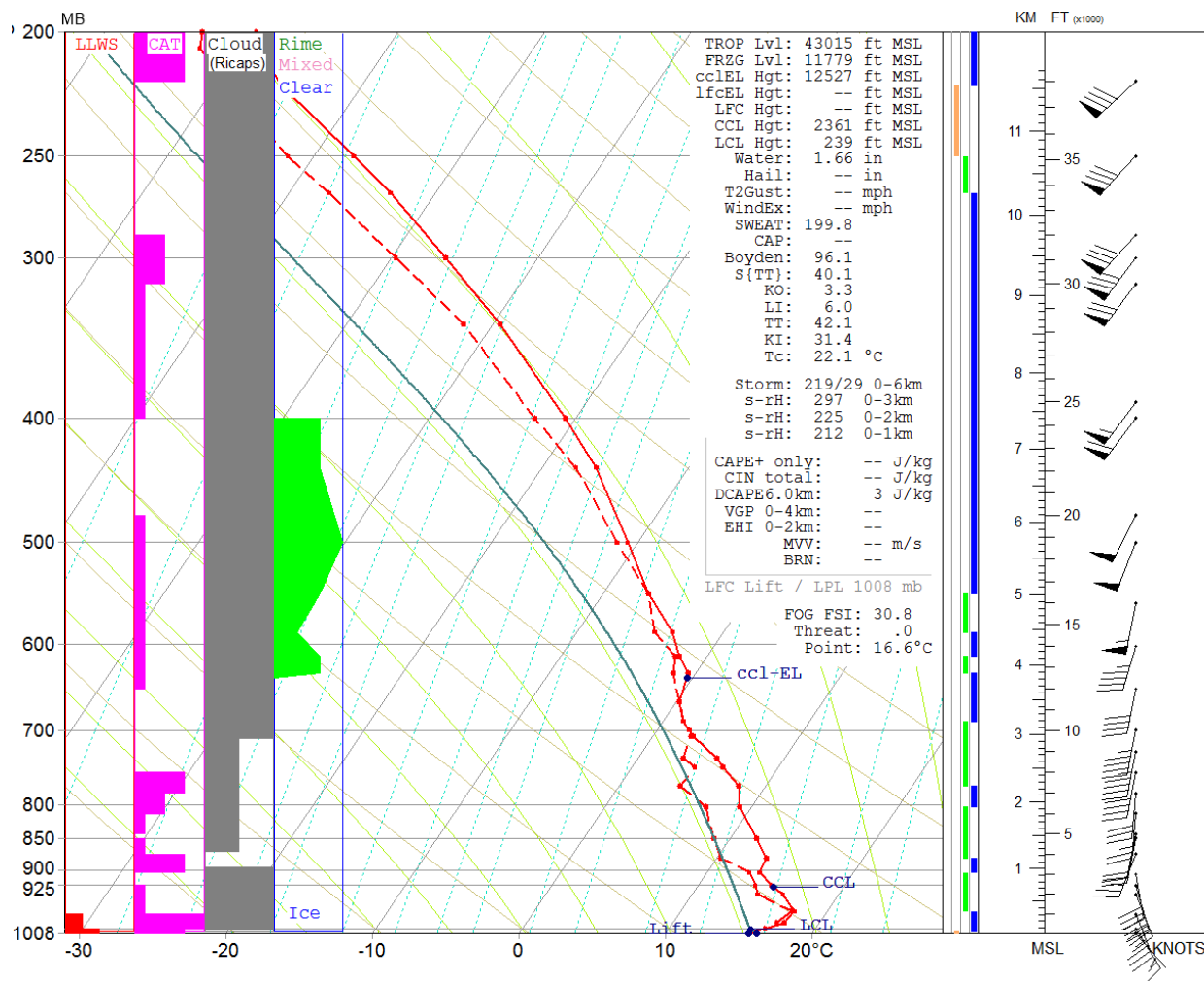


Figure 11 – 0700 EST KJAX sounding

The 0700 EST KJAX sounding indicated alternating layers of conditional instability and a stable environment from the surface through 17,000 ft msl, then a stable environment from 17,000 ft msl through 33,500 ft msl. RAOB identified the possibility of clouds between 1,000 ft msl through 40,000 ft. Moderate rime icing was indicated by RAOB between 14,000 ft msl and 24,000 ft msl. Icing potential will be further discussed in section 19.0.

The 0700 EST KJAX sounding wind profile indicated a surface wind from 140° at 3 knots with the wind remaining southeasterly through 4,000 ft msl. The wind increased in speed to 30 knots by 4,000 ft msl. The wind veered¹⁰ to the southwest above 4,000 ft with increasing wind speeds through 40,000 ft. The wind was from 205° at 51 knots between 20,000 and 22,000 ft msl. RAOB indicated a high probability of moderate or greater clear-air turbulence between the surface and 8,000 ft msl. At the accident airplane's altitude before descent¹¹ around 23,000 ft, the sounding indicated a southwest wind at 51 knots with a temperature of -16.3° C, and with a relative humidity of 89%.

¹⁰ A change in wind direction with height in a clockwise sense in the Northern Hemisphere

¹¹ For more information please see the NTSB ATC information in the docket for this accident.

5.0 Satellite Data

The Geostationary Operational Environmental Satellite number 16 (GOES-16) visible and infrared data were obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System software. Visible and infrared imagery (GOES-16 bands 2 and 13) at wavelengths of 0.64 microns (μm) and $10.3 \mu\text{m}$, respectively, were retrieved for the period from 0600 EST through 1200 EST and reviewed, and the closest images to the time of the accident were documented.

Figures 12 and 13 present the GOES-16 visible imagery at 0900 and 0905 EST at 2X magnification with the last ATC target point highlighted with a red square. The visible imagery indicated an extensive layer of cloud cover cumuliform in nature over the last ATC target point with the cloud cover moving from southwest to northeast (attachment 1).

Figure 14 presents the GOES-16 infrared imagery from 0905 EST at 4X magnification with the last ATC target point highlighted with a red square. Inspection of the infrared imagery indicated cloud cover over the accident site. The lower brightness temperatures (blue and green colors; higher cloud tops) were located above and to the north and south of the last ATC target point (attachment 2) with the cloud cover moving from southwest to northeast. Based on the brightness temperatures above the accident site and the vertical temperature profile provided by the 0700 EST KJAX sounding, the approximate cloud-top heights over the accident site were 33,000 ft at 0905 EST (232° Kelvin). In addition, there were areas where the cover cloud tops over KJAX were 24,000 ft at 0905 EST (254° Kelvin). It should be noted these figures have not been corrected for any parallax error.

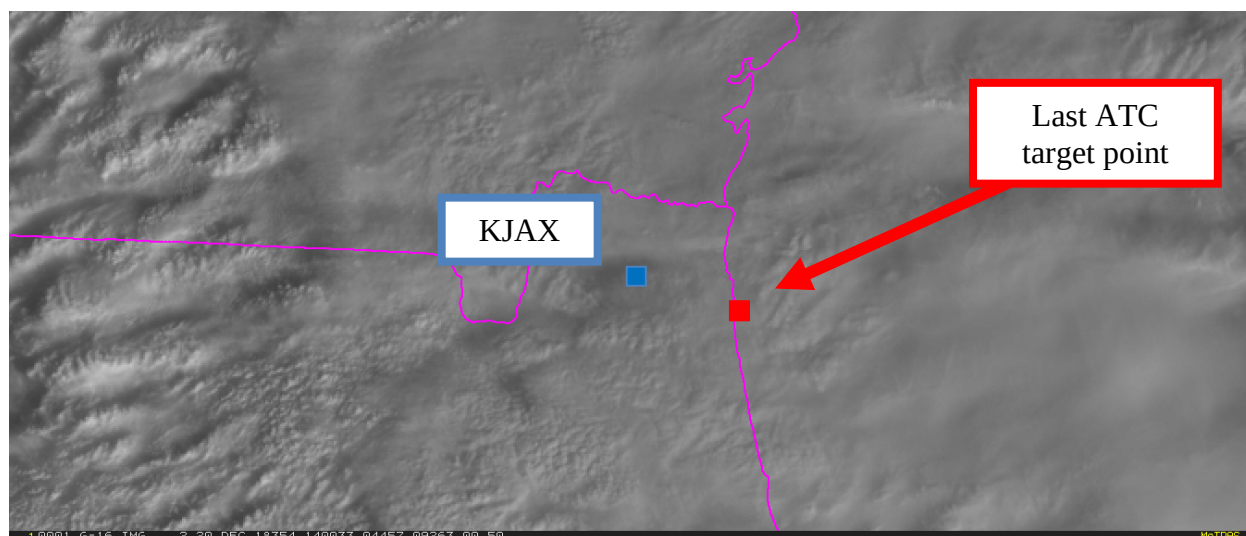


Figure 12 – GOES-16 visible image at 0900 EST

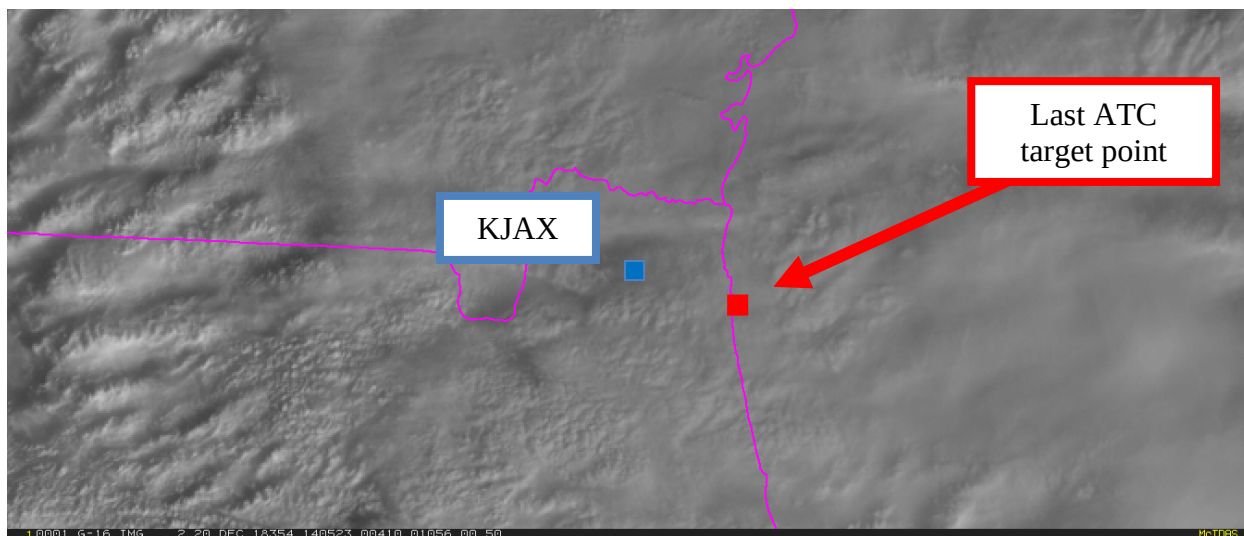


Figure 13 – GOES-16 visible image at 0905 EST

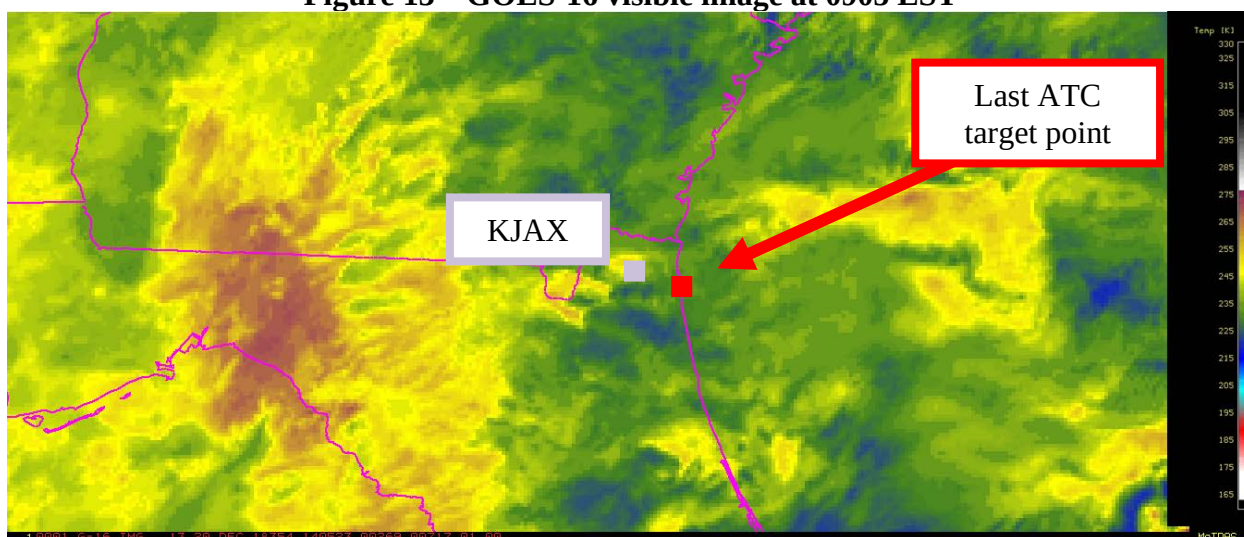


Figure 14 – GOES-16 infrared image at 0905 EST

6.0 Regional Radar Imagery Information

A regional view of the NWS national composite radar mosaic is included as figure 15 for 0905 EST with the approximate location of the last ATC target point marked by a red circle. The image depicted echoes from 35 to 50 decibels (dBZ¹²) echoes in the immediate vicinity of the last ATC target point.

¹² 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.

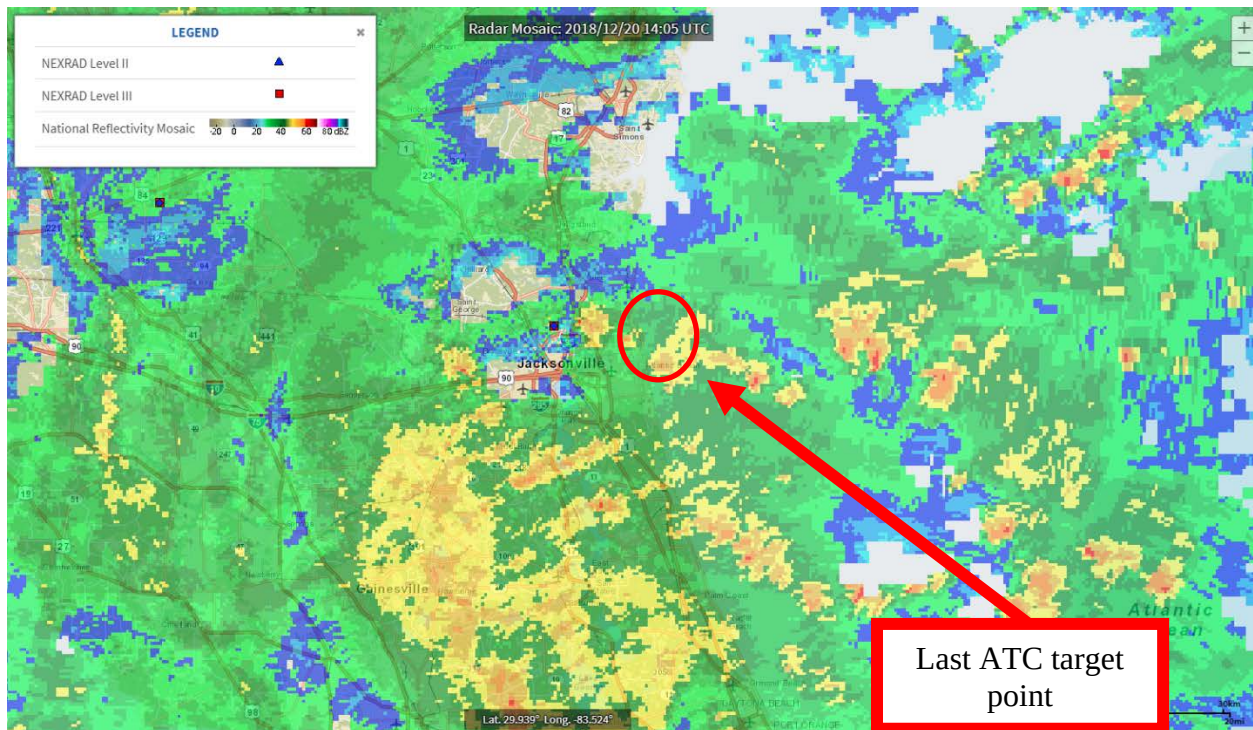


Figure 15 – Regional Composite Reflectivity image for 0905 EST

7.0 Radar Imagery Information

The closest NWS Weather Surveillance Radar-1988, Doppler (WSR-88D)¹³ to the accident site was KJAX (with antenna elevation of 159 ft). Data from Moody Air Force Base, Georgia, (KVAX) was also reviewed and used for this investigation. KVAX was located 88 miles west-northwest of the accident site at an elevation of 330 ft. Level II and level III archive radar data was obtained from the NCEI utilizing the NEXRAD Data Inventory Search and displayed using the NOAA's Weather and Climate Toolkit software.

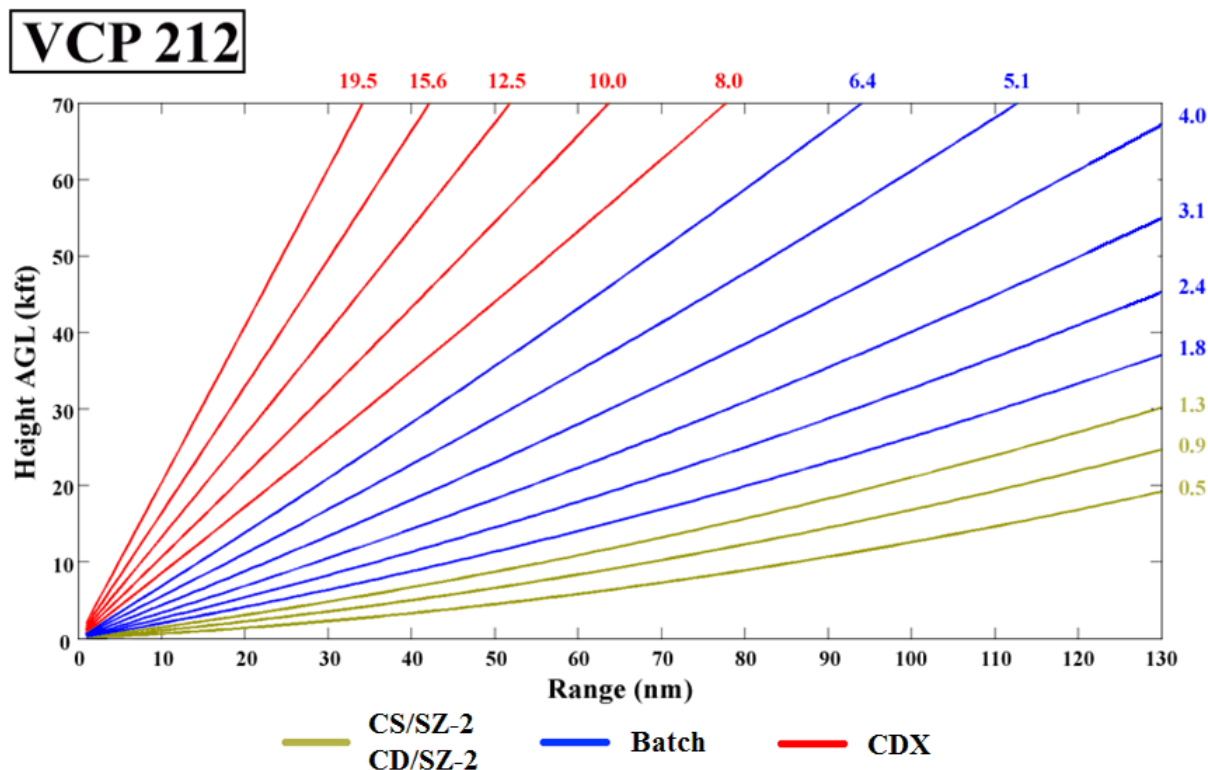
7.1 Volume Scan Strategy

The WSR-88D is a computer-controlled radar system, which automatically creates a complete series of specific scans in a specific sequence known as a volume scan. Individual elevation scans are immediately available. Products that require data from multiple elevation scans are not available until the end of the five to ten-minute volume scan.

The WSR-88D operates in several different scanning modes, identified as Mode A and Mode B. Mode A is the precipitation scan and has three common scanning strategies. The most common is where the radar makes 14 elevation scans from 0.5° to 19.5° every four and a half minutes. This particular scanning strategy is documented as volume coverage pattern 212 (VCP-212). Mode B is the clear-air mode, where the radar makes 5 elevation scans during a ten-minute period. During

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.

the period surrounding the accident, the KJAX WSR-88D radar was operating in the precipitation mode VCP-212. The following chart provides an indication of the different elevation angles in this VCP, and the approximate height and width of the radar beam with distance from the radar site.



VCP-212 Precipitation Mode Scan Strategy¹⁴

7.2 Beam Height Calculation

Assuming standard refraction¹⁵ of the WSR-88D radar beam with the antenna elevation at 159 ft (KJAX), and considering a beamwidth¹⁶ of 0.95°, the following table shows the approximate heights for the radar beam center, top and base for antenna elevations over the accident site. These heights have been rounded to the nearest 10 ft.

¹⁴ 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)

¹⁵ Standard Refraction in the atmosphere is when the temperature and humidity distributions are approximately average, and values set at the standard atmosphere.

¹⁶ Beamwidth - the angular separation between the half power points on the antenna radiation pattern, where the gain is one half the maximum value.

ANTENNA ELEVATION	BEAM CENTER	BEAM BASE	BEAM TOP
KJAX 10.0°	18,250 ft	17,420 ft	19,080 ft
KJAX 12.5°	22,650 ft	21,830 ft	23,470 ft
KVAX 1.3°	18,050 ft	13,710 ft	22,390 ft

Based on the radar height calculations, the elevation scans from both KJAX and KVAX listed in the above table depicted the conditions between 13,710 ft and 22,650 ft msl over the accident aircraft's position and these scans "saw" the closest altitudes to the accident aircraft's flight level before descent in altitude beginning at 0902:04 EST.¹⁷

7.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors¹⁸ it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in dBZ, and is a general measure of echo intensity. FAA Advisory Circular AC 00-24C¹⁹, "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

¹⁷ For more information please see ATC data located in the docket of this accident.

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

¹⁹

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

7.4 Base Reflectivity and Lightning Data

Figures 16, 17, 18, and 19 present the KJAX WSR-88D base reflectivity images for the 10.0° and 12.5° elevation scans initiated at 0859:10, 0904:05, 0859:23, and 0904:18 EST, respectively, with a resolution of 0.5° X 250 m. Reflectivity values between 10 and 30 dBZ were located above the last ATC target point at the accident time and along the accident aircraft's flight track (pink line). The reflectivity bands were moving from south to north (attachment 3).

There were no lightning strikes around the last ATC target point at the accident time.²⁰

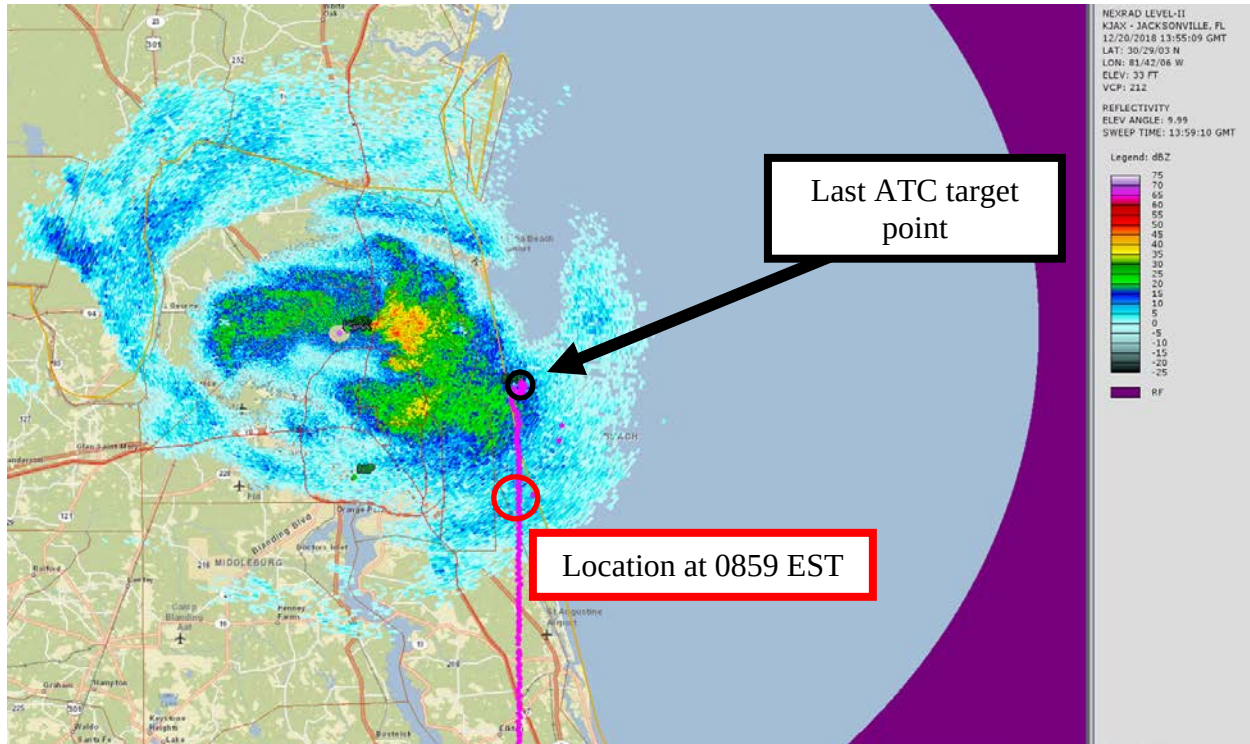


Figure 16 – KJAX WSR-88D reflectivity for the 10.0° elevation scan initiated at 0859:10 EST with the last ATC target point marked with black circle, the accident flight track in pink

²⁰ A review of Earth Networks Total Lightning network was done.

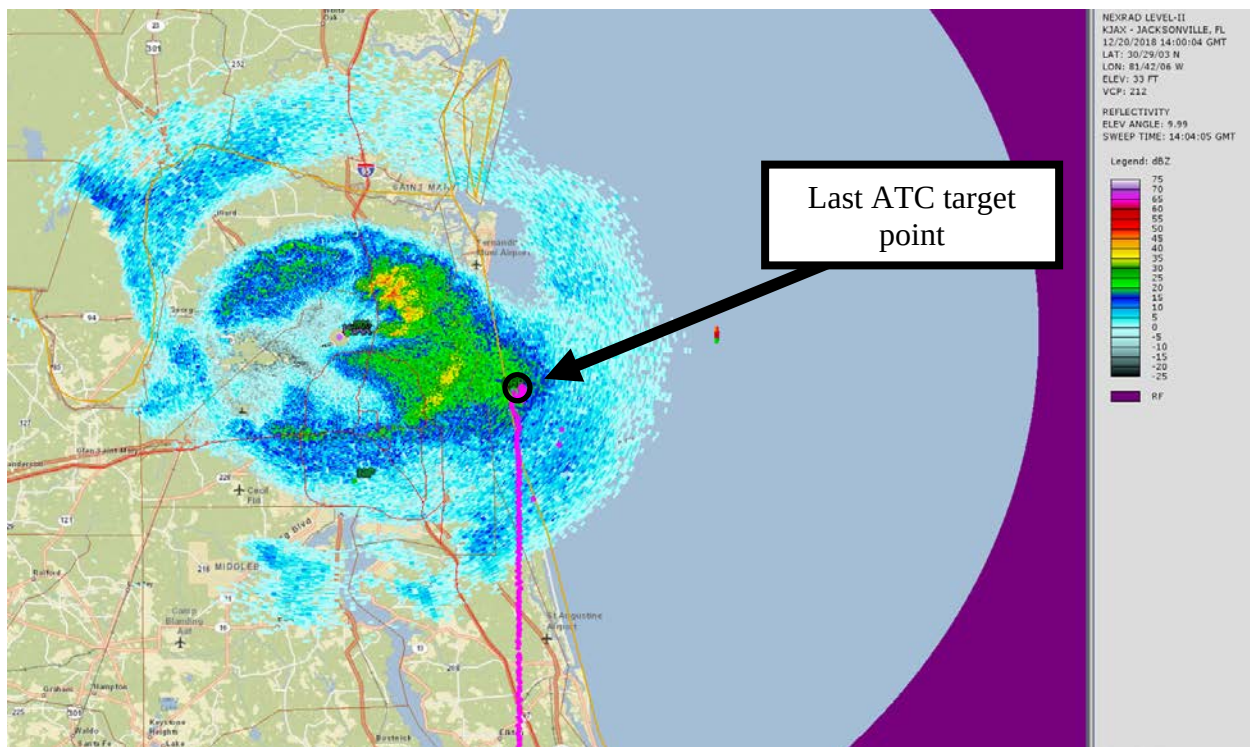


Figure 17 – KJAX WSR-88D reflectivity for the 10.0° elevation scan initiated at 0904:05 EST with the last ATC target point marked with black circle, the accident flight track in pink

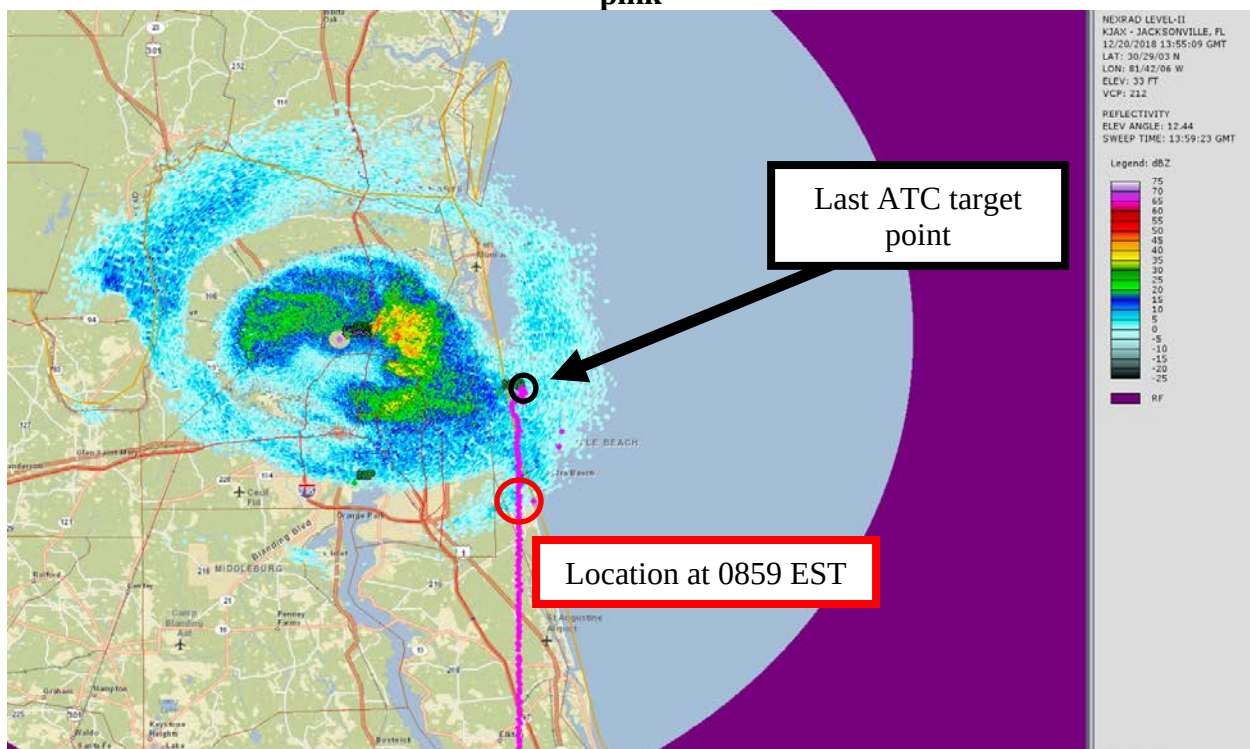


Figure 18 – KJAX WSR-88D reflectivity for the 12.5° elevation scan initiated at 0859:23 EST with the last ATC target point marked with black circle, the accident flight track in pink

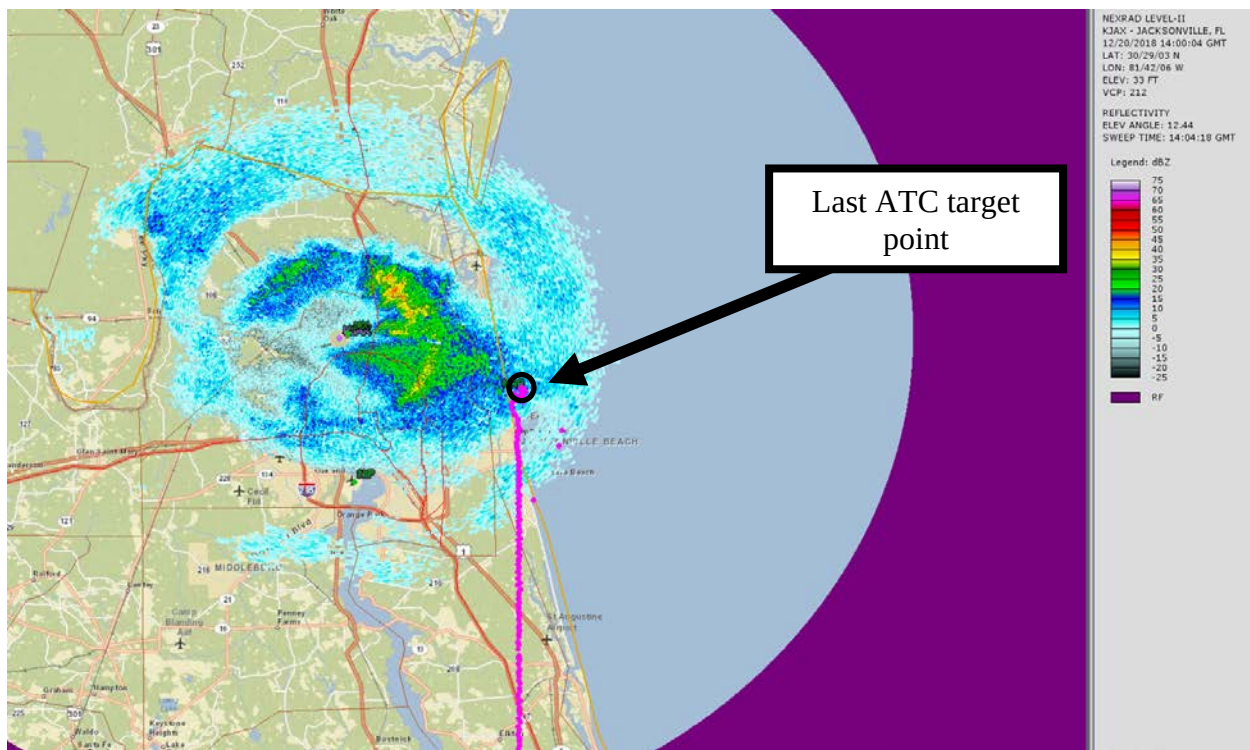


Figure 19 – KJAX WSR-88D reflectivity for the 12.5° elevation scan initiated at 0904:18 EST with the last ATC target point marked with black circle, the accident flight track in pink

7.5 Dual-Pol Products²¹

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

Differential Reflectivity (Zdr) is the logarithm ratio of the horizontal power return to the vertical power return. Positive values of Zdr indicate that there is more horizontal power return than vertical power return.²² A negative value of Zdr indicates that there is more vertical power return than horizontal power return indicating that the dominant hydrometeors are larger in the vertical than in the horizontal.²³ Near zero values of Zdr indicate that both the horizontal and vertical power return from within the volume scanned are of similar values, meaning the dominant hydrometeors are similar in size in both the vertical and horizontal.²⁴

Correlation Coefficient (CC) is a measure of how similar the horizontal and vertical returned pulse characteristics are among all pulses in the sampled WSR-88D volume. CC provides information about the diversity of hydrometeors within the volume and the values range from 0 to

²¹ Definitions for Zdr, CC, KDP, and HC adapted from training material from the NWS WDTD.

²² A positive Zdr means that the dominant hydrometeors within the volume are larger in the horizontal than vertical (e.g., rain drops).

²³ A negative Zdr correlates to vertically oriented hydrometeors, e.g., vertically oriented crystals or conical graupel.

²⁴ A near zero Zdr is often an indication of hail or spherical rain drops.

1.²⁵ Meteorological echoes tend to have CC values greater than 0.80, with values greater than 0.96 indicating that the meteorological targets within the volume are all very similar in size, shape, type (liquid versus solid), and orientation. CC values between 0.96 and 0.80 indicate that the meteorological targets within the volume have a higher diversity of sizes, shapes, types, and orientations as the CC trends lower. If hail is located within the volume scanned the CC values are typically between 0.80 and 0.96. Non-meteorological echoes have CC values less than 0.80 and these non-meteorological echoes can include, but are not limited to, bugs, chaff, smoke and birds.

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

Hydrometeor Classification (HC) is a product produced by the hydrometeor classification algorithm and the HC attempts to discriminate between 10 classes of radar echoes at every 250 m range bin. HC ingests reflectivity, Zdr, CC, KDP, and velocity, along with radially averaged and smoothed fields of reflectivity and differential phase. HC then uses the height of the melting layer along with other WSR-88D data and assigns a radar class to each bin with a weighted value. The HC then applies a set of hard thresholds to reduce the number of clearly wrong class designations, and given the weight and likelihood of each of the 10 classes at each bin, the HC assigns the radar classification with the highest likelihood value to that particular bin.

7.6 Dual-Pol Imagery

Figures 20, 21, and 22 present the level III KVAX WSR-88D base reflectivity, Zdr, and CC values for the 1.3° elevation scans initiated at 0854:27, 0859:33, and 0904:48 EST with a resolution of 1° X 1 kilometer.

Figure 20 depicted light echoes in the base reflectivity at the aircraft location at 0854 EST with 10 to 20 dBZ values. The Zdr values were between -0.25 and 1.0 dB and CC values ranged between 0.97 and 0.99. These values of dual-pol data at the aircraft location and along the flight path indicated small hydrometeor sizes, and/or a small amount of hydrometeors in the beam, hydrometeors that were more horizontally shaped as they fell than spherical, and the majority of the hydrometeors in the scan near the aircraft location 0854 EST had similar characteristics.

Figure 21 depicted light to moderate echoes in the base reflectivity at the aircraft location at 0859 EST with 20 to 30 dBZ values. The Zdr values were between 0.0 and 1.0 dB and CC values ranged between 0.96 and 0.99. These values of dual-pol data at the aircraft location and along the

²⁵ CC values greater than 1 indicate an untrustworthy signal due to low signal-to-noise ratio in areas of weak reflectivity.

flight path indicated small hydrometeor sizes, and/or a small amount of hydrometeors in the beam, hydrometeors that were more horizontally shaped as they fell than spherical, and the majority of the hydrometeors in the scan near the aircraft location 0859 EST had similar characteristics.

Figure 22 depicted light to moderate echoes in the base reflectivity at the last ATC target position at 0904 EST with 20 to 30 dBZ values. The Zdr values were between -0.25 and 1.0 dB and CC values ranged between 0.97 and 0.99. These values of dual-pol data at the aircraft location and along the flight path indicated small hydrometeor sizes, and/or a small amount of hydrometeors in the beam, hydrometeors that were more horizontally shaped as they fell than spherical, and the majority of the hydrometeors in the scan near the last ATC target point had similar characteristics.

The dBZ values remained in the light to moderate echo value range with CC values consistently between 0.97 and 0.99 for the majority of the accident flight track, and the Zdr values ranged toward more horizontally shaped hydrometeors. With the higher Zdr values, the accident aircraft would have encountered hydrometeors having a larger surface area in the horizontal dimension rather than the vertical dimension, meaning the hydrometeors were shaped more like pancakes, rather than spherical or tear dropped shaped as the hydrometeors fell.²⁶ For more information and animations please see attachments 4, 5, and 6.

²⁶ Ikeda, Kyoko, Roy M. Rasmussen, Edward Brandes, and Frank McDonough, 2009: Freezing Drizzle Detection with WSR-88D Radars (Journal of Applied Meteorology and Climatology, 48), pp. 41-60.

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

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

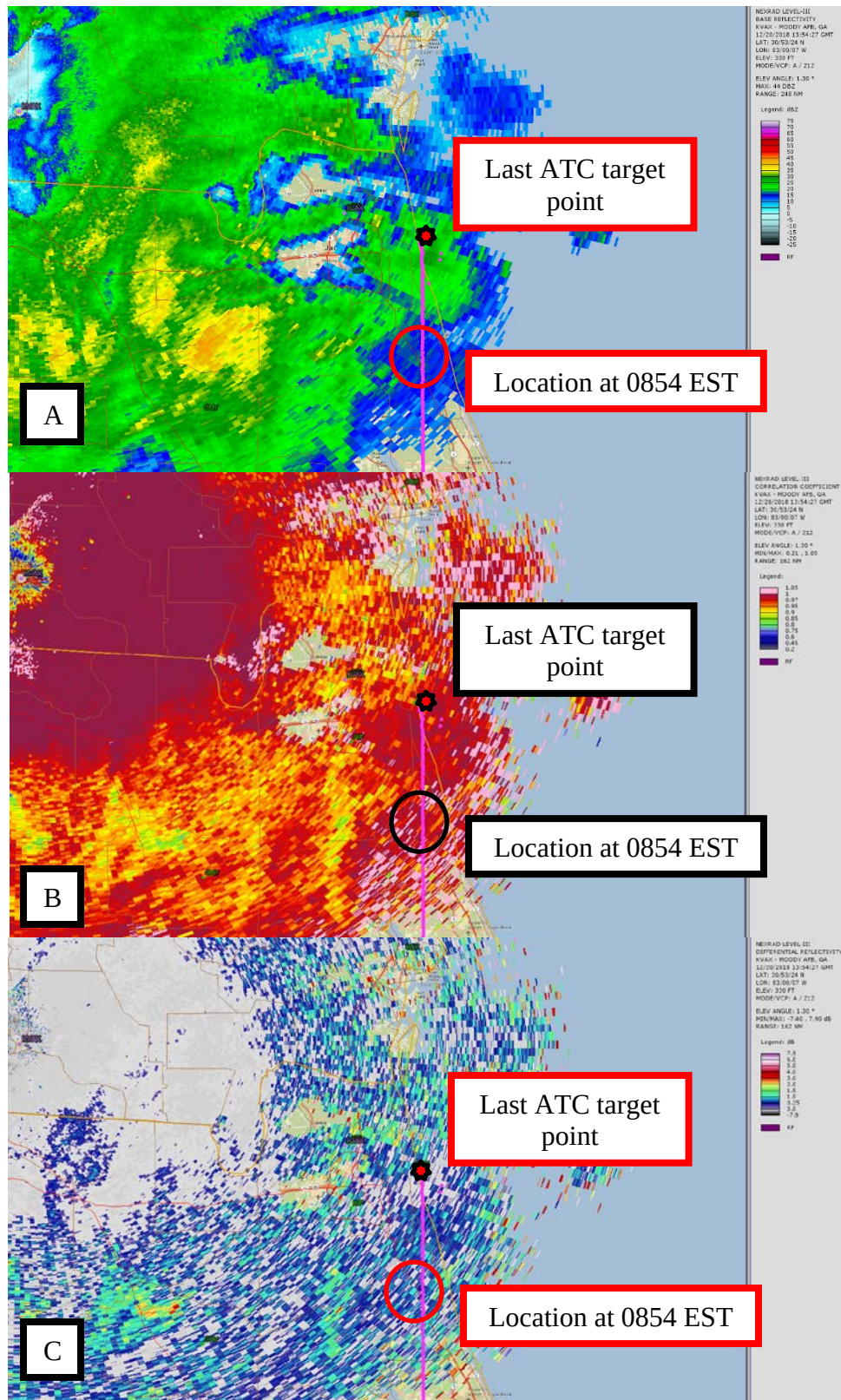


Figure 20 – KVAX WSR-88D 1.3° elevation scan for 0854:27 EST (a) base reflectivity, (b) CC, and (c) Zdr with the last ATC target point marked with a circle and the accident flight track in pink

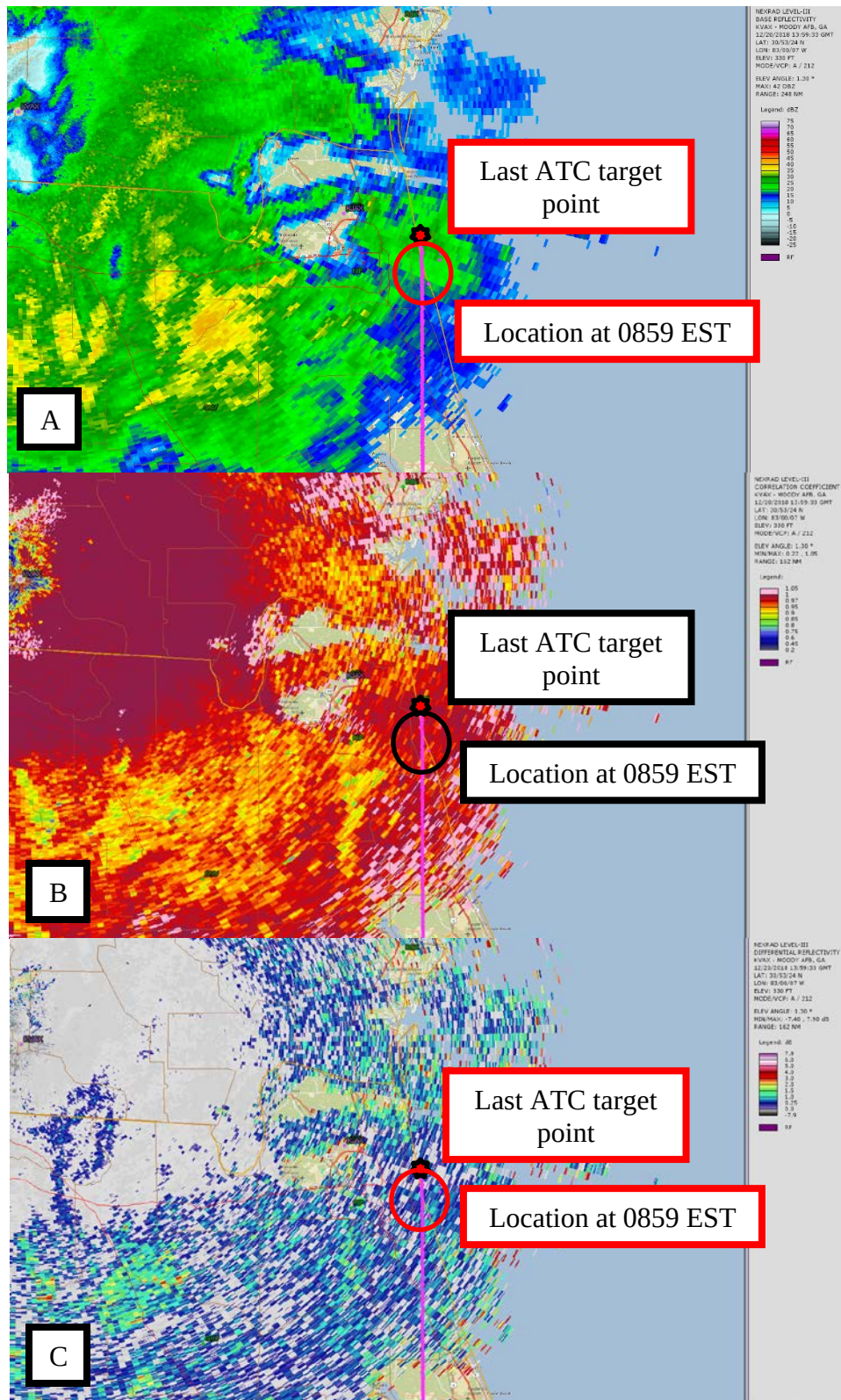


Figure 21 – KVAX WSR-88D 1.3° elevation scan for 0859:33 EST (a) base reflectivity, (b) CC, and (c) Zdr with the last ATC target point marked with a circle and the accident flight track in pink

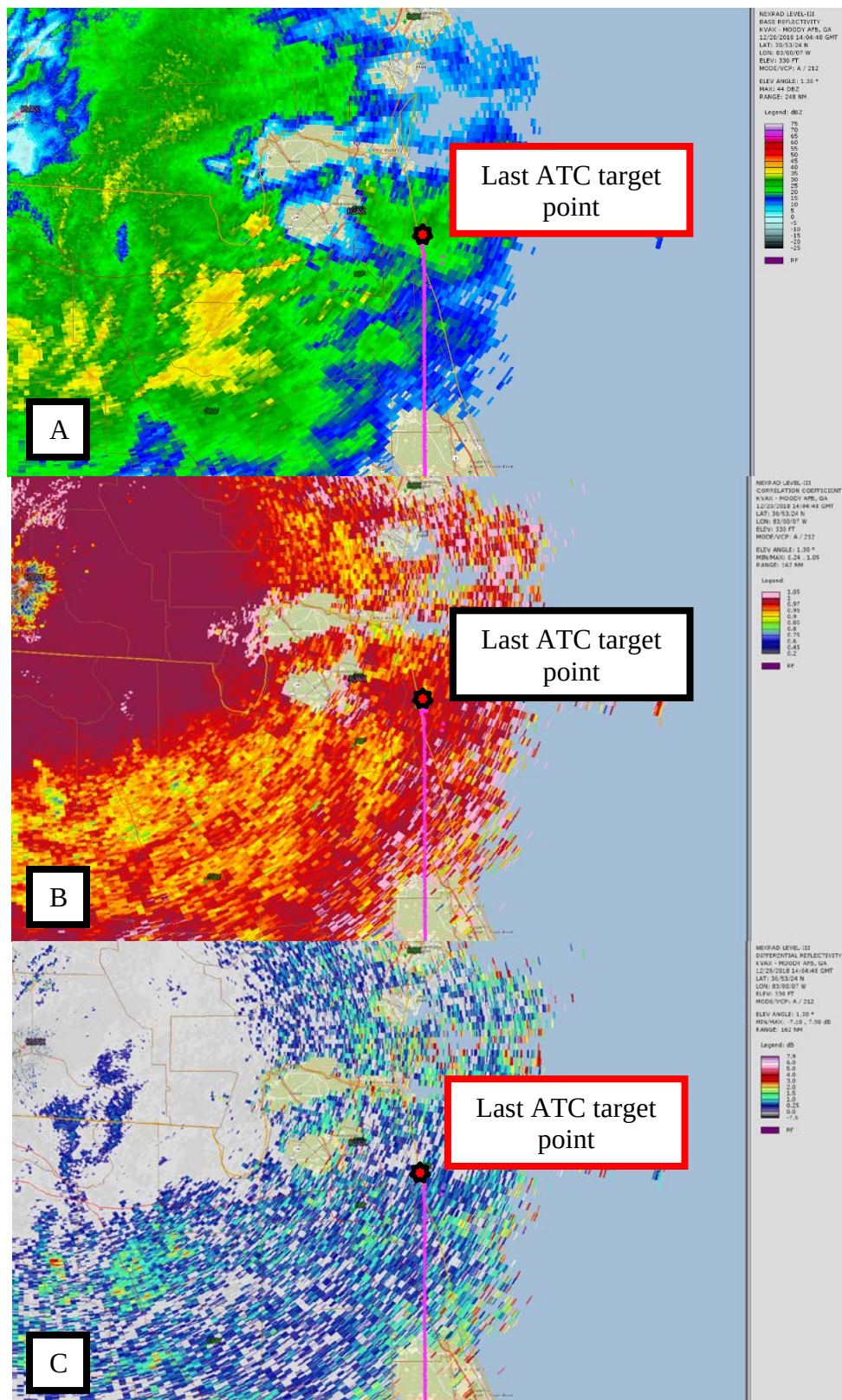


Figure 22 – KVAX WSR-88D 1.3° elevation scan for 0904:48 EST (a) base reflectivity, (b) CC, and (c) Zdr with the last ATC target point marked with a circle and the accident flight track in pink

8.0 Pilot Reports²⁷

All pilot reports (PIREPs) within 100 miles of the accident site from about one hour prior to the accident time to about one hour after the accident time for below FL300²⁸ are provided below:

GNV UA /OV GNV/TM 1325/FL210/TP A306/TA M11/IC LGT-MOD RIME

JAX UA /OV SGJ135002/TM 1330/FL007/TP C560/SK BKN007/RM MPOD RA

GNV UA /OV CTY125040/TM 1341/FL230/TP C560/TA 00/IC LGT RIME

JAX UA /OV FHB/TM 1345/FL005/TP LJ45/SK SCT005/RM MARGINAL VFR

GNV UA /OV GNV200020/TM 1345/FL250/TP B737/TA M24/IC MOD RIME

JAX UA /OV GNV/TM 1350/FL007/TP C560/SK BKN007/RM MOD RA

OCF UA /OV OCF300025/TM 1353/FL160/TP PC12/TA M12/IC MOD RIME

GNV UA /OV GNV270010/TM 1353/FL260/TP B738/TA M27/IC LGT-MOD RIME

GNV UA /OV GNV070015/TM 1355/FL240/TP B752/TA M20/TB CONT LGT CHOP/IC LGT RIME

GNV UA /OV GNV270010/TM 1356/FL240/TP B738/TA M24/IC MOD RIME

CRG UA /OV CRG140010/TM 1430/FL230/TP C525/TB INTMT LGT CHOP/IC NEG

OMN UA /OV OMN340020/TM 1430/FL240/TP B737/TB MOD

GNV UA /OV OCF130020/TM 1439/FL190/TP B752/TA M10/IC LGT RIME 190-170

DAB UA /OV OMN/TM 1453/FL030/TP CRJ9/TB LGT-MOD/RM -RA

GNV UA /OV GNV350030/TM 1505/FL170/TP B757/TA M08/IC LGT MX

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

Routine pilot report (UA) Gainesville Regional Airport, Florida (GNV); Over GNV; Time – 0825 EST (1325Z); Altitude – FL210; Type aircraft – Airbus A-300-600; Temperature – -11° C; Icing – Light to moderate rime.

Routine pilot report (UA) Jacksonville International Airport, Florida (JAX); Over 2 miles from St. Augustine, Florida, (SGJ) VORTAC on the 135° radial; Time – 0830 EST (1330Z); Altitude –

²⁷ Only pilot reports with the World Meteorological Organization headers UBFL** and UBGA** were considered.

²⁸ Flight Level – A Flight Level (FL) is a standard nominal altitude of an aircraft, in hundreds of ft. This altitude is calculated from the International standard pressure datum of 1013.25 hPa (29.92 inHg), the standard 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.

700 ft; Type aircraft – Cessna Citation V; Sky – Broken clouds at 700 ft; Remarks – Moderate rain.

Routine pilot report (UA) GNV; Over 40 miles from Cross City, Florida, (CTY) VORTAC on the 125° radial; Time – 0841 EST (1341Z); Altitude – FL230; Type aircraft – Cessna Citation V; Temperature – 0° C; Icing – Light rime.

Routine pilot report (UA) JAX; Over Fernandina Beach, Florida, (FHB); Time – 0845 EST (1345Z); Altitude – 500 ft; Type aircraft – Learjet 45; Sky – Scattered clouds at 500 ft; Remarks – Marginal VFR conditions.

Routine pilot report (UA) GNV; Over 20 miles from GNV on the 200° radial; Time – 0845 EST (1345Z); Altitude – FL250; Type aircraft – Boeing 737-700; Temperature – -24° C; Icing – Moderate rime.

Routine pilot report (UA) JAX; Over GNV; Time – 0850 EST (1350Z); Altitude – 700 ft; Type aircraft – Cessna Citation V; Sky – Broken clouds at 700 ft; Remarks – Moderate rain.

Routine pilot report (UA) Ocala International Airport, Florida, (OCF); Over 25 miles from OCF on the 300° radial; Time – 0853 EST (1353Z); Altitude – 16,000 ft; Type aircraft – Pilatus PC-12; Temperature – -12° C; Icing – Moderate rime.

Routine pilot report (UA) GNV; Over 10 miles from GNV on the 270° radial; Time – 0853 EST (1353Z); Altitude – FL260; Type aircraft – Boeing 737-800; Temperature – -27° C; Icing – Light to moderate rime.

Routine pilot report (UA) GNV; Over 15 miles from GNV on the 070° radial; Time – 0855 EST (1355Z); Altitude – FL240; Type aircraft – Boeing 757-200; Temperature – -20° C; Turbulence – Continuous light chop; Icing – Light rime.

Routine pilot report (UA) GNV; Over 10 miles from GNV on the 270° radial; Time – 0856 EST (1356Z); Altitude – FL240; Type aircraft – Boeing 737-800; Temperature – -24° C; Icing – Moderate rime.

Routine pilot report (UA) Jacksonville Executive Airport, Florida, (CRG); Over 10 miles from CRG on the 140° radial; Time – 0930 EST (1430Z); Altitude – FL230; Type aircraft – Cessna 525 Citation Jet; Turbulence – Intermittent light chop; Icing – Negative.

Routine pilot report (UA) Ormond Beach Municipal Airport, Florida, (OMN); Over 20 miles from OMN on the 340° radial; Time – 0930 EST (1430Z); Altitude – FL240; Type aircraft – Boeing 737-700; Turbulence – Moderate.

Routine pilot report (UA) GNV; Over 20 miles from OCF on the 130° radial; Time – 0939 EST (1439Z); Altitude – FL190; Type aircraft – Boeing 757-200; Temperature – -10° C; Icing – Light rime between 19,000 and 17,000 ft.

Routine pilot report (UA) Daytona Beach International Airport, Florida, (DAB); Over OMN; Time – 0953 EST (1453Z); Altitude – 3,000 ft; Type aircraft – Bombardier CRJ-900; Turbulence – Light to moderate; Remarks – Light rain.

Routine pilot report (UA) GNV; Over 30 miles from GNV on the 350° radial; Time – 1005 EST (1505Z); Altitude – 17,000 ft; Type aircraft – Boeing 757; Temperature – -8° C; Icing – Light mixed.

9.0 SIGMET

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

10.0 CWSU Products

The Air Route Traffic Control Center Jacksonville (KZJX) Center Weather Service Unit (CWSU) was responsible for the region. The KZJX CWSU issued no Meteorological Impact Statements (MIS) for the area prior to the accident. The KZJX CWSU had Center Weather Advisory (CWA) 201 at 0822 EST and was valid until 0922 EST for area at the time of the accident. The advisory warned of a developing area of thunderstorms moving from 200° at 40 knots. Thunderstorm tops were to FL300 with heavy rainfall and an increasing trend (figure 23):

FAUS22 KZJX 201322

ZJX2 CWA 201322

ZJX CWA 201 VALID UNTIL 201422

FROM 190S FLO-225S CHS-80N TRV-25WSW CRG-190S FLO

DVLPG AREA TS MOV FM 20040KT. TOPS TO FL300. HVY RAINFALL. INCRG TREND.

=

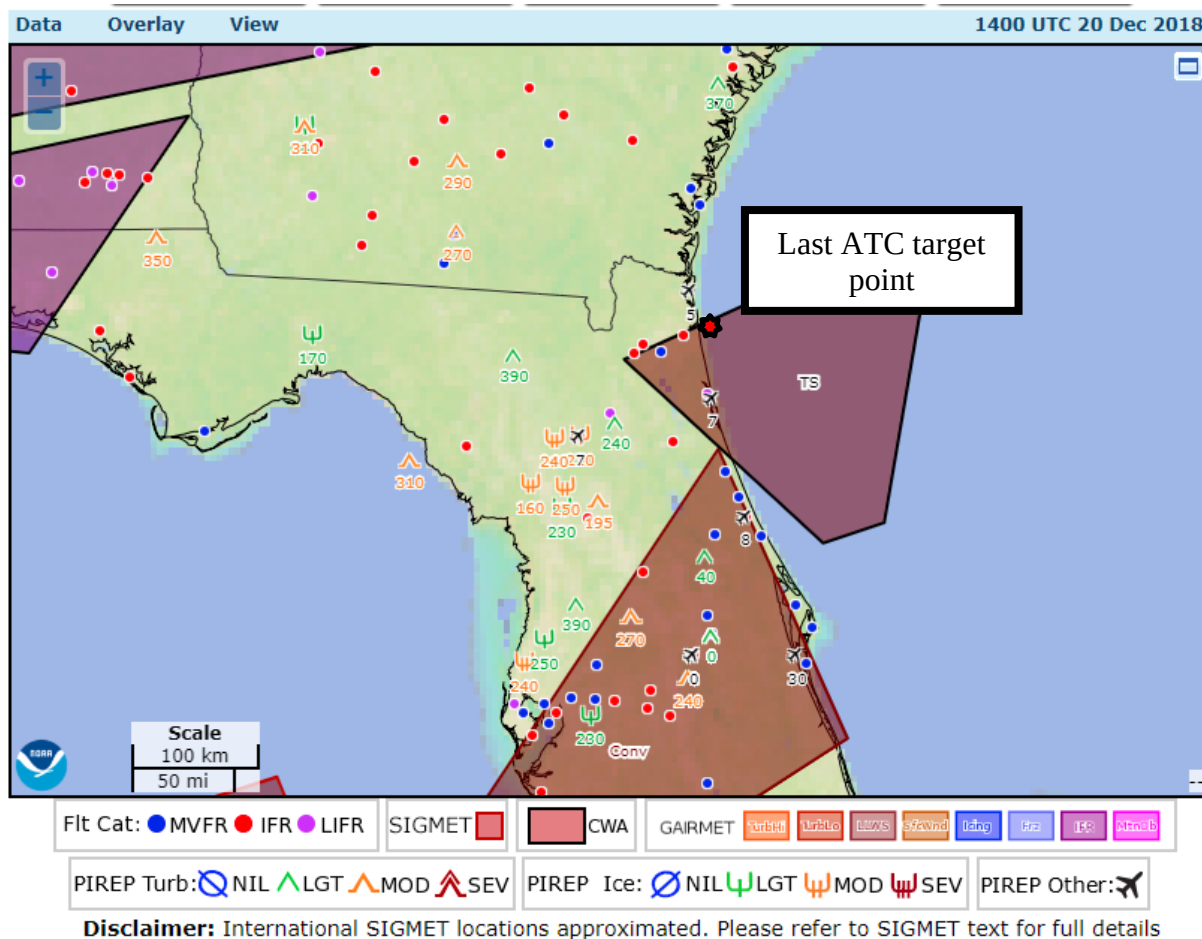


Figure 23 – SIGMETs and CWAs valid at 0900 EST

11.0 AIRMETs

Airmen's Meteorological Information (AIRMET) advisories Sierra, Tango, and Zulu were valid for the accident flight's track and last ATC target point at the accident time. The AIRMETs warned of IFR²⁹ conditions due to precipitation and mist, moderate icing between the freezing level³⁰ and FL270, moderate turbulence below FL180, moderate turbulence between FL220 and FL390, and LLWS expected:

WAUS42 KPCI 200845
 WA2S
 -MIAS WA 200845
 AIRMET SIERRA UPDT 1 FOR IFR AND MTN OBSCN VALID UNTIL 201500
 .
**AIRMET IFR...NC SC GA FL WV MD VA AND CSTL WTRS
 FROM 20ESE SBY TO 40ENE ORF TO 60S ECG TO CHS TO 30NE CRG TO TRV**

²⁹ Instrument Flight Rules (IFR) – Refers to the general weather conditions pilots can expect at the surface. IFR criteria means a ceiling below 1,000 ft agl and/or less than 3 miles visibility.

³⁰ Freezing level between 11,000 and 14,000 ft.

**TO SRQ TO 30WSW CTY TO 70SSE SJI TO 40W CEW TO 50SW PZD TO GQO
TO HNV TO 20ESE SBY
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG BYD 15Z THRU 21Z.**

.
AIRMET MTN OBSCN...NC SC GA PA WV MD VA
FROM JST TO EMI TO LYH TO GSO TO CLT TO ATL TO GQO TO HNV TO
50WSW BKW TO JST
MTNS OBSC BY CLDS/PCPN/BR. CONDS CONTG BYD 15Z THRU 21Z.

.
OTLK VALID 1500-2100Z
AREA 1...IFR NC SC GA FL NY NJ PA OH WV MD DC DE VA AND CSTL WTRS
BOUNDED BY 50E PSB-40S JFK-50SSE ECG-50ESE CRG-TRV-SRQ-50SSW CEW-
120ESE LEV-40W CEW-50SW PZD-GQO-HNV-HNN-JST-50E PSB
CIG BLW 010/VIS BLW 3SM PCPN/BR. CONDS CONTG THRU 21Z.

.
AREA 2...MTN OBSCN NC SC GA NY PA WV MD VA
BOUNDED BY 60ESE BUF-ETX-CLT-ATL-GQO-HNV-HNN-EWC-60ESE BUF
MTNS OBSC BY CLDS/PCPN/BR. CONDS CONTG THRU 21Z.

....

WAUS42 KKCI 200845
WA2T
-MIAT WA 200845
AIRMET TANGO UPDT 1 FOR TURB STG WNDZ AND LLWS VALID UNTIL 201500

.
**AIRMET TURB...NC SC GA FL AND CSTL WTRS
FROM 70E ORF TO 90S ECG TO 20N PBI TO 90WSW PIE TO 170SE LEV TO
130ESE LEV TO 40W CEW TO 50SW PZD TO GQO TO HNV TO 20NE ECG TO
70E ORF
MOD TURB BTN FL220 AND FL390. CONDS CONTG BYD 15Z THRU 21Z.**

.
**AIRMET TURB...NC SC GA FL AND CSTL WTRS
FROM 50SSW VXV TO 20N FLO TO 50E TRV TO 20NW EYW TO 110WNW EYW
TO 90WSW PIE TO 170SE LEV TO 20N CEW TO 50SW PZD TO 40WNW ATL TO
50SSW VXV
MOD TURB BLW FL180. CONDS DVLPG 09-12Z. CONDS CONTG BYD 15Z THRU
21Z.**

.
AIRMET STG SFC WNDZ...FL AND CSTL WTRS
FROM 70SW TLH TO 30W CTY TO 50SSW RSW TO 80WSW EYW TO 90WSW PIE
TO 160W PIE TO 80S CEW TO 70SW TLH
SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS CONTG BYD 15Z
ENDG 18-21Z.

.
**LLWS POTENTIAL...SC GA FL AND CSTL WTRS
BOUNDED BY 30SE ODF-40ESE FLO-120ENE OMN-30NE PBI-20S SRQ-90SSW
TLH-50SW PZD-20W MCN-30SE ODF
LLWS EXP. CONDS CONTG BYD 15Z THRU 21Z.**

.
OTLK VALID 1500-2100Z
AREA 1...TURB NC SC GA FL ME NH VT MA RI CT NY LO NJ PA OH LE WV
MD DC DE VA AND CSTL WTRS
BOUNDED BY 70NW PQI-60NE PQI-110SSW YSJ-ACK-70E ORF-110SSE ILM-
40E MIA-110WNW EYW-90WSW PIE-170SE LEV-130ESE LEV-40W CEW-50SW
PZD-GQO-HNV-HNN-CVG-FWA-30SE ECK-YOW-YSC-70NW PQI
MOD TURB BTN FL220 AND FL390. CONDS CONTG THRU 21Z.

.
AREA 2...TURB NC SC GA FL WV MD VA AND CSTL WTRS
BOUNDED BY 20S HNN-30WSW SBY-80S ECG-60NE PBI-60SSE MIA-90WNW
EYW-90WSW PIE-200S CEW-20WNW CEW-50SW PZD-GQO-HMV-20S HNN
MOD TURB BLW FL180. CONDS CONTG THRU 21Z.

.
AREA 3...STG SFC WND S NC SC GA FL AND CSTL WTRS
BOUNDED BY 50S ILM-130SSE ILM-200ENE TRV-40ESE TRV-40SE OMN-50S
SAV-50S ILM
SUSTAINED SURFACE WINDS GTR THAN 30KT EXP. CONDS DVLPG 15-18Z.
CONDS CONTG THRU 21Z.

....

WAUS42 KKCI 200845
WA2Z
-MIAZ WA 200845
AIRMET ZULU UPDT 1 FOR ICE AND FRZLVL VALID UNTIL 201500

.
AIRMET ICE...NC SC GA FL OH WV VA AND CSTL WTRS
FROM HNN TO 50ESE EKN TO 20NNE TLH TO 170S CEW TO 130ESE LEV TO
40W CEW TO 50SW PZD TO GQO TO HMV TO HNN
MOD ICE BTN FRZLVL AND FL240. FRZLVL 080-100. CONDS ENDG BY 15Z.

.
**AIRMET ICE...NC SC GA FL RI NY NJ OH WV MD DE VA AND CSTL WTRS
FROM 50ESE EKN TO 30SSE CSN TO 190S ACK TO 160SE SIE TO 190ESE
ECG TO 130SSE ILM TO 200ENE PBI TO 40NW MIA TO 40W RSW TO 170S
CEW TO 20NNE TLH TO 50ESE EKN
MOD ICE BTN FRZLVL AND FL270. FRZLVL 110-140. CONDS CONTG BYD 15Z
THRU 21Z.**

.
FRZLVL...RANGING FROM 095-160 ACRS AREA
120 ALG 210S CEW-40WNW CTY-CRG-60ESE OMN-100NE TRV-110ESE ECG-
180E ECG

....

12.0 Graphical Forecasts for Aviation

The Graphical Forecasts for Aviation (GFA) products made available before the accident flight are shown in attachment 7. The GFA surface forecast products indicated MVFR surface visibilities at the last ATC target point with likely (greater than 60 percent chance) rain shower activity and a southerly surface wind at 30 knots. The GFA cloud forecast valid before departure for around the accident time indicated overcast skies at 2,100 ft to 8,000 ft with clouds top between FL200 and FL410. AIRMETs Sierra and Zulu were also located on the figures. For more information please see attachment 7.

13.0 Terminal Aerodrome Forecast

KCRG was the closest airport to the accident site with a NWS Terminal Aerodrome Forecast (TAF). KCRG was located 8 miles west-southwest of the last ATC target point with an elevation of 41 ft (figure 10). The KCRG TAF valid at the time of the accident was issued at 0812 EST and was valid for a 23-hour period beginning at 0800 EST. The TAF for KCRG was as follows:

KCRG 201312Z 2013/2112 18011G20KT 3SM RA BR SCT007 OVC040
TEMPO 2013/2014 2SM +SHRA BR BKN007
FM201400 15014G22KT 2SM +RA BR BKN007 OVC035
FM201800 18014G22KT 2SM -RA BR OVC006
FM210000 24006G12KT 2SM -RA BR OVC004
FM210300 21010G15KT 6SM -DZ BR BKN050 OVC100=

Between 0900 and 1300 EST, the forecast expected a wind from 150° at 14 knots with gusts to 22 knots, 2 miles visibility, heavy rain and mist, a broken ceiling at 700 ft agl, and overcast skies at 3,500 ft agl.

14.0 NWS Area Forecast Discussion

The NWS office in Jacksonville, Florida, issued the following Area Forecast Discussion (AFD) at 0342 EST (closest AFD to the accident time). The aviation section of the AFD discussed MVFR to IFR conditions with potential for a band of thunderstorms to move across the local airports in the region during the late morning through the evening hours:

FXUS62 KJAX 200845 CCA
AFDJAX

Area Forecast Discussion
National Weather Service Jacksonville FL
342 AM EST Thu Dec 20 2018

...INTENSE LOW PRESSURE SYSTEM WILL BRING WIDESPREAD HEAVY RAINFALL
AND POTENTIAL SEVERE WEATHER ON THURSDAY...

...VERY WINDY CONDITIONS ARE EXPECTED ON FRIDAY AS ALL-TIME RECORD
LOW SEA LEVEL PRESSURES POSSIBLE FOR THE MONTH OF DECEMBER...

.NEAR TERM.../through tonight/...

Rest of tonight...light rain will continue across the north
Florida and southeast Georgia area overnight with some heavier
rainfall beginning to work in from the Crystal river area across
over to Ocala and Palatka for the morning commute. Shouldn't see
much in the way of fog overnight with the exception of some
evaporation fog in areas of heavier rainfall.

Today...A sharp upper level ridge will drop southward into the
Mississippi River Valley with a surface low developing ahead of it
over the Florida Panhandle. A strong low level jet will move
across the area and especially over the southern portions of the
region tomorrow afternoon. So the first band of thunderstorms
should develop south of State Road 16 during the late morning and
move northeast toward the Jacksonville Metro area. Later in the
afternoon that axis should begin to shift south to the Ocala to St
Augustine area. This is a favored area based on climatology for
severe convection and tornadoes in this type of synoptic pattern
and would not be surprised to see strong rotating cells across the
Ocala National Forest into the Flagler county area later in the
afternoon. So not going to regenerate the SPC day one outlook here

but would refer you to it and the enhance wording for the central Florida peninsula and believe it applies to that extreme southern portion of our forecast area as well.

Tonight...as an intense, for our latitude, low pressure area takes shape along the AL-GA state line the squall line will move offshore with mainly low cloudiness and light rainfall overnight. Will have a brief period of time in the dry slot but that will not last long as the 850 trough begins to migrate over the area returning the low cloudiness over the area. Winds will remain in the 10 to 15 mph range overnight so fog should be limited to areas of ongoing precipitation.

&&

.SHORT TERM.../Friday through Sunday night/...

Friday...As the low begins to pull into South Carolina as about a 985 mb low near Greenville-Spartanburg the gradient flow around the low will be strong with the area reaching wind advisory criteria. Am concerned that occasional gusts in the 40 to even 50 mph could be experienced in large open areas and especially the ports and estuaries. While we have Gale Warning offshore we may still see gale force gusts in the ports of Jacksonville, Fernandina and Brunswick.

&&

.LONG TERM.../Monday through Wednesday/...

High pressure will begin to weaken on Monday as a trough begins to develop across southern Georgia. This will result in showers developing on Tuesday for the northern portions of the forecast region with the prevailing flow becoming more southerly by Wednesday, along with greater potentials for rainfall. High temperatures will range between the 60s and 70s, with overnight low temperatures increasing from the 40s on Monday to into the mid to high 50s by Wednesday.

&&

.AVIATION...

Overall the morning hours will be flirting with MVFR to IFR conditions but after 15 to 18 utc expect all of the fields to drop to IFR conditions and stay there for the rest of the day. Between 15 and 03 utc should see bands of thunderstorms move across the fields and especially the most southern areas around KGNV and KSGJ. Have covered the timing of the convection with a Prob30 group but the day shift will have to tweak the timing as the system develops. Tonight will see a brief improvement as the dry slot moves across the region but that will be very quickly replaced by the 925-850 mb trough and low cloudiness and light rain/drizzle. I didn't try to time the dry slot just bear in mind that any improvement will be brief.

&&

.MARINE...

Southeast flow to increase tonight to 15 to 20 knots as Small Craft Advisory conditions develop this morning. Southerly flow increases ahead of intensifying low pressure system to 20 to 30 knots with occasional gusts to gale force possible by the afternoon, with even stronger wind gusts with storm activity pushing offshore during the afternoon and evening hours. Seas building to 8-10 ft offshore and 5-7 ft nearshore.

With very intense low pressure passing just NW of the waters on Thu Night and Friday, Gale Warnings have been issued.

Rip Currents: High Risk today, Moderate Risk Friday.

&&

.HYDROLOGY...

Flood Watch is on track for today with widespread heavy rainfall developing this morning and continuing through the day with 2-3 inch rainfall amounts expected across NE FL and 1-2.5 inch rainfall amounts across SE GA. This will further exacerbate river flooding with multiple basins likely reaching Moderate to locally Major flood stages by this weekend and into next week.

&&

.CLIMATE...

All-Time December Sea Level Pressure Records at the Climate Sites
JAX 997.3mb 12-07-1875 GNV 998.3mb 12-18-2009 AMG 996.6mb 12-18-2009
SSI 997.2mb 12-18-2009

Daily Sea Level Pressure Records for Thu 12/20 and Fri 12/21 JAX
1001.4mb 12-20-1892, 999.0mb 12-21-1878 GNV 1007.0mb 12-20-1995,
1007.0mb 12-21-1993 SSI 1004.1mb 12-20-1995, 1005.4mb 12-21-1993 AMG
1008.0mb 12-20-1995, 1010.4mb 12-21-1993

All-Time December Wind Gust Records at the Climate Sites JAX 62
mph/12-10-1997 GNV 46 mph/12-24-2014 AMG 50 mph/12-31-1975 SSI 45
mph/12-07-2011

Daily Wind Gust Records For Thu 12/20 and Fri 12/21 JAX 51 mph/12-20-
1905, 41 mph/12-21-1973 GNV 30 mph/12-20-2012, 36 mph/12-21-1978 AMG
41 mph/12-20-2012, 35 mph/12-21-2012 SSI 35 mph/12-20-1974, 36
mph/12-21-2008

&&

.PRELIMINARY POINT TEMPS/POPS...

AMG 67 53 58 40 / 100 90 40 10
SSI 68 54 61 40 / 100 90 40 10

JAX 69 55 61 40 / 100 90 30 0
SGJ 71 55 63 40 / 100 90 40 0
GNV 69 54 60 39 / 100 90 50 0
OCF 71 55 61 40 / 100 90 60 10

&&

.JAX WATCHES/WARNINGS/ADVISORIES...

FL...Flood Watch through Friday morning for Alachua-Baker-Bradford-
Clay-Coastal Duval-Coastal Flagler-Coastal Nassau-Coastal
St. Johns-Columbia-Gilchrist-Hamilton-Inland Duval-Inland
Flagler-Inland Nassau-Inland St. Johns-Marion-Putnam-
Suwannee-Union.

GA...Flood Watch through Friday morning for Atkinson-Charlton-Clinch-
Echols-Ware.

AM...Small Craft Advisory until 10 AM EST this morning for Coastal
waters from Altamaha Sound to Fernandina Beach FL out 20 NM-
Coastal waters from Fernandina Beach to St. Augustine FL
out 20 NM-Coastal waters from St. Augustine to Flagler
Beach FL out 20 NM-Waters from Altamaha Sound GA to
Fernandina Beach FL from 20 to 60 NM-Waters from Fernandina
Beach to St. Augustine FL from 20 to 60 NM-Waters from St.
Augustine to Flagler Beach FL from 20 to 60 NM.

Gale Warning from 10 AM this morning to 4 AM EST Saturday for
Coastal waters from Altamaha Sound to Fernandina Beach FL
out 20 NM-Coastal waters from Fernandina Beach to St.
Augustine FL out 20 NM-Coastal waters from St. Augustine to
Flagler Beach FL out 20 NM-Waters from Altamaha Sound GA to
Fernandina Beach FL from 20 to 60 NM-Waters from Fernandina
Beach to St. Augustine FL from 20 to 60 NM-Waters from St.
Augustine to Flagler Beach FL from 20 to 60 NM.

&&

\$\$

15.0 NWS Special Marine Warning

The NWS office in Jacksonville, Florida, issued the following Special Marine Warning (SMW) at 0902 EST (valid through 1030 EST) for an area east of Jacksonville, Florida, which included the last ATC target point. The SMW warned of a severe thunderstorm capable of producing waterspouts moving northward at 60 knots with surface wind gusts greater than 34 knots as well:

WHUS52 KJAX 201402
SMWJAX
AMZ452-454-472-201530-
/O.NEW.KJAX.MA.W.0233.181220T1402Z-181220T1530Z/

BULLETIN - IMMEDIATE BROADCAST REQUESTED
Special Marine Warning
National Weather Service Jacksonville FL

902 AM EST THU DEC 20 2018

The National Weather Service in Jacksonville has issued a

* Special Marine Warning for...

Coastal waters from Fernandina Beach to St. Augustine FL out 20 NM...

Coastal waters from St. Augustine to Flagler Beach FL out 20 NM...

Waters from Fernandina Beach to St. Augustine FL from 20 to 60 NM...

* **Until 1030 AM EST.**

* **At 902 AM EST, a severe thunderstorm capable of producing waterspouts was located near Saint Augustine Beach, or near Saint Augustine, moving north at 60 knots.**

HAZARD...Waterspouts and wind gusts 34 knots or greater.

SOURCE...Radar.

IMPACT...Waterspouts can easily overturn boats and create locally hazardous seas. Small craft could be damaged in briefly higher winds and suddenly higher waves.

* Locations impacted include...

Atlantic Beach, Dorothy Louise Barge, Saint Augustine Beach, Mayport, Nassau Sound Approach Buoy 6a, Beverly Beach, Anna Reef, Vilano Beach, Amelia City, Palm Coast, South Ponte Vedra Beach, Palm Valley, Nine Mile Reef, Saint Augustine, Jacksonville Beach, Crescent Beach, Talbot Island, Saint Johns Lighted Buoy, Butler Beach and Marineland.

PRECAUTIONARY/PREPAREDNESS ACTIONS...

Thunderstorms can produce sudden waterspouts. Waterspouts can easily overturn boats and create locally hazardous seas. Seek safe harbor immediately.

&&

LAT...LON 2946 8116 2953 8120 2954 8122 3066 8152
3061 8090 2991 8093 2991 8094 2972 8087
2969 8085 2948 8075

TIME...MOT...LOC 1402Z 180DEG 59KT 2984 8119

WATERSPOUT...POSSIBLE

HAIL...0.00IN

WIND...>34KTS

\$\$

16.0 Winds and Temperature Aloft Forecast

The NWS 0857 EST Winds and Temperature Aloft forecast valid for the closest point to the last ATC target point is included below:

```
FBUS31 KWN0 201357
FD1US1
DATA BASED ON 201200Z
VALID 201800Z   FOR USE 1400-2100Z. TEMPS NEG ABV 24000

FT  3000    6000    9000   12000   18000   24000   30000   34000   39000

JAX 2045 2057+11 2164+07 2166+02 2166-09 2166-20 227036 229247 730053
```

The accident site was located closest to the JAX forecast point. The 0857 EST JAX forecast for use between 0900 EST and 1600 EST indicated a wind at 12,000 ft from 210° at 66 knots with a temperature of 2° C, a wind at 18,000 ft from 210° at 66 knots with a temperature of -9° C, and a wind at 24,000 ft from 210° at 66 knots with a temperature of -20° C.

17.0 Pilot Weather Briefing

The accident pilot did not request a weather briefing from Leidos, however, Leidos did archive the ForeFlight documents the accident pilot requested at 0717 EST on the day of the accident (attachments 8, 9, 10).

A search of archived ForeFlight information indicated that the accident pilot did request weather information via ForeFlight.com (attachment 11) at 0717 EST. The weather briefing information contained all the standard weather information valid at 0717 EST, including a convective SIGMET “outlook” area valid along the route of flight, AIRMETs, surface analysis chart, current METARs valid along the route of flight, PIREPs, GFA forecast, TAFs, and winds aloft. Prior to departure the accident pilot looked at multiple other routes and altitudes for the flight with 9 different routes and altitudes picked between 0713 and 0809 EST (attachment 11). The accident pilot did not access any weather imagery via ForeFlight mobile prior to the accident flight on the accident day, but could have accessed text information. There is no record of the accident pilot receiving or retrieving any other weather information before or during the accident flight.

18.0 CWSU Weather Briefing for ATC

The KZJX CWSU provide a pre-duty weather briefing at 0545 EST for the ATC personnel at ZJX. The ATC personnel on duty at the time of the accident would have had to view this pre-duty weather briefing prior to their first shift of the day. The CWSU pre-duty weather briefing contained all the standard weather forecast information valid at 0545 EST, including SIGMET and AIRMET information, “active” TAFs, and discussion of the weather forecast for ZJX airspace through the day (attachment 12).

19.0 Icing Potential³¹³²

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 24 through 26 are the FIP icing probabilities and icing severity products, 1-hour forecast valid at 0900 EST at 19,000, 21,000, and 23,000 ft msl. Even higher FIP icing probabilities and severities values are seen in the 2-hour forecast valid at both 0800 and 0900 EST (and the 1-hour forecast valid at 0800 EST) between 18,000 and 23,000 ft (attachment 13) as those higher FIP icing values are associated with the abundant cumuliform precipitation along the route of flight (sections 5.0, 6.0, and 7.4). The FIP images in figures 24 through 26 indicated between a 10 to 40% probability of icing at 19,000 to 23,000 ft at 0900 EST above the last ATC target point (figures 24, 25, and 26). The FIP also indicated that the icing near the last ATC target point would likely be light to moderate (figures 24, 25, and 26). The FIP did not indicate any probability of Supercooled Large Droplets (SLD) over the last ATC target point around the accident time on the SLD composite imagery (attachment 13). The higher probabilities of SLD were located over areas where the FIP had a higher probability of icing in the cumuliform clouds (attachment 13). FIP information was publicly available on the NWS AWC website before the accident flight departed.³³

The CIP product indicated between a 10 to 50% probability of icing at 19,000 to 23,000 ft at 0900 EST at the last ATC target point (figures 27, 28, and 29). The CIP also indicated that the icing near the last ATC target point would likely be light intensity between 19,000 and 23,000 ft (figures 27, 28, and 29). The CIP also indicated an unknown probability of SLD near the accident site at 0900 EST between 19,000 and 23,000 ft (attachment 13). The higher probabilities of icing and severity were located over areas where the CIP had a higher probability of icing in the cumuliform clouds with heavy icing indicated at 18,000 to 20,000 ft at 0800 EST at the last ATC target point (attachment 13). For more FIP and CIP data please see attachments 13. For FIP and CIP data available at the time of the weather briefing (section 17.0) please see attachment 16.

³¹ B.C. Bernstein, F. McDonough, M. K. Politovich, B. G. Brown, T. P. Ratvasky, D. R. Miller, C.A. Wolff, and G. Cuning, 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. Cuning, FIP Severity Technical Document (Prepared for the Aviation Weather Technology Transfer Technical Review Board), pp. 1-44.
<https://arc.aiaa.org/doi/abs/10.2514/6.2009-3531>

³² S.G. Cober, G. A. Isaac, and J. W. Strapp, Characterizations of Aircraft Icing Environments that Include Supercooled Large Drops (Journal of Applied Meteorology, 2001), pp. 1984-2002.

B.C. Bernstein, C.A. Wolff, and F. McDonough, An Inferred Climatology of Icing Conditions Aloft, Including Supercooled Large Drops. Part I: Canada and the Continental United States (Journal of Applied Meteorology and Climatology, 2007), pp. 1857-1878.

Williams, E.R., D.J. Smalley, M.F. Donovan, R.G. Hallowell, K.T. Hood, B.J. Bennett, R. Evaristo, A. Stepanek, T. Bals-Elsholz, J. Cobb, J. Ritzman, A. Korolev, M. Wolde, Measurements of Differential Reflectivity in Snowstorms in Warm Season Stratiform Systems (Journal of Applied Meteorology and Climatology, 2015), pp. 573-595.

³³ <https://www.aviationweather.gov/icing/fip>

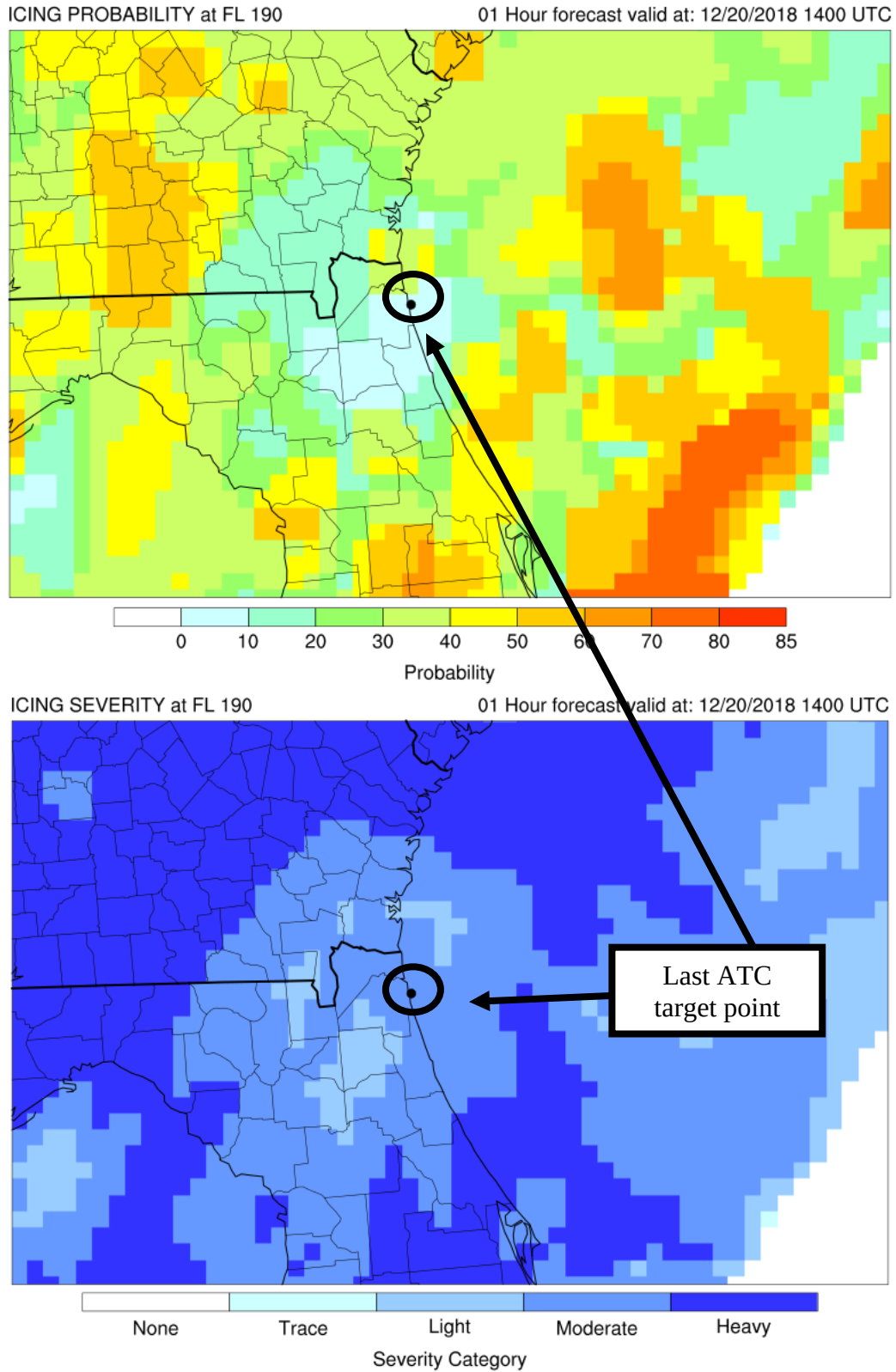
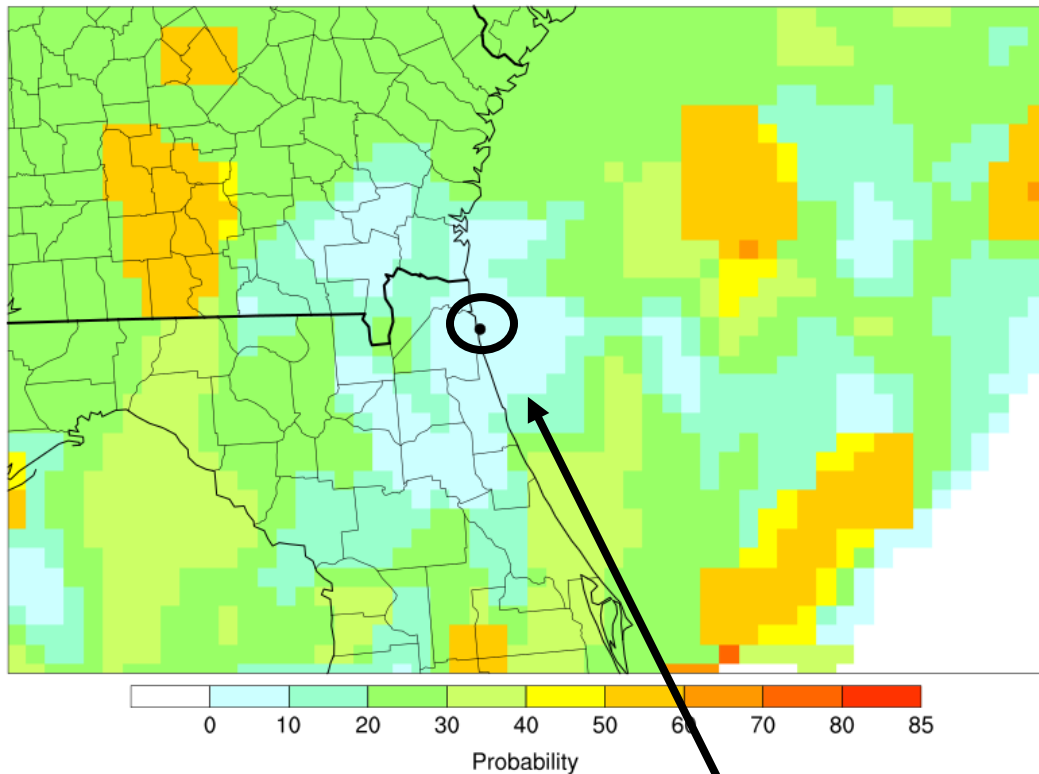


Figure 24 – (top) FIP probability of icing at 19,000 ft msl and (bottom) FIP severity of icing at 19,000 ft msl 1-hour forecast valid for 0900 EST

ICING PROBABILITY at FL 210

01 Hour forecast valid at: 12/20/2018 1400 UTC



ICING SEVERITY at FL 210

01 Hour forecast valid at: 12/20/2018 1400 UTC

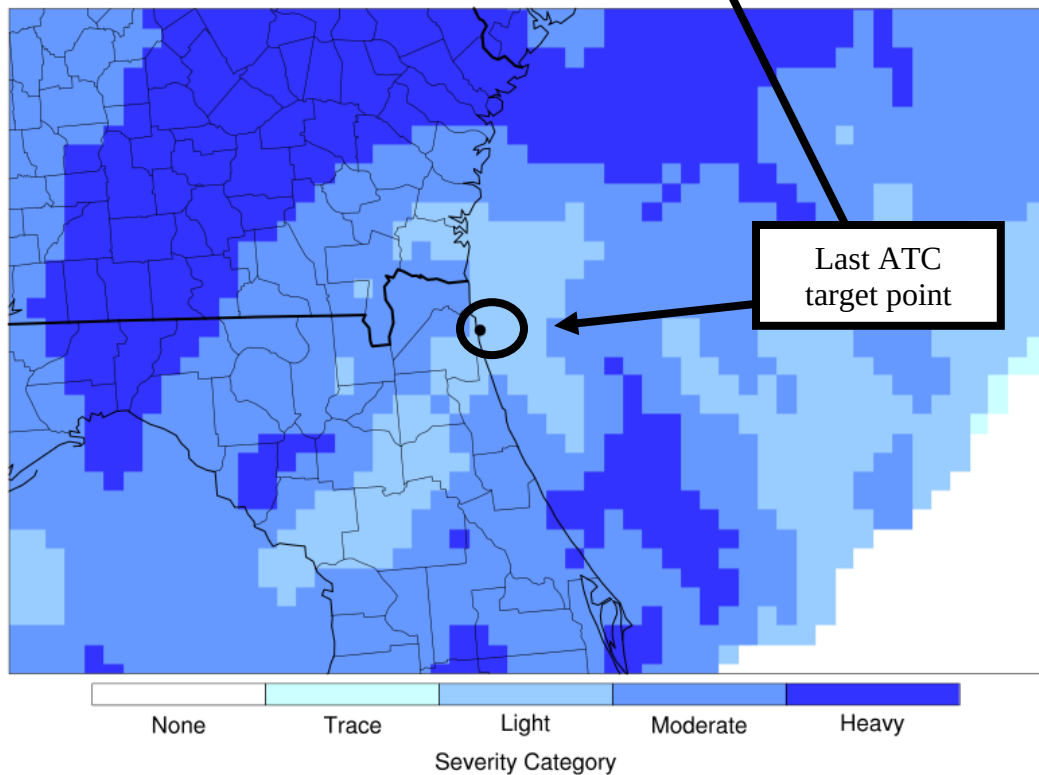
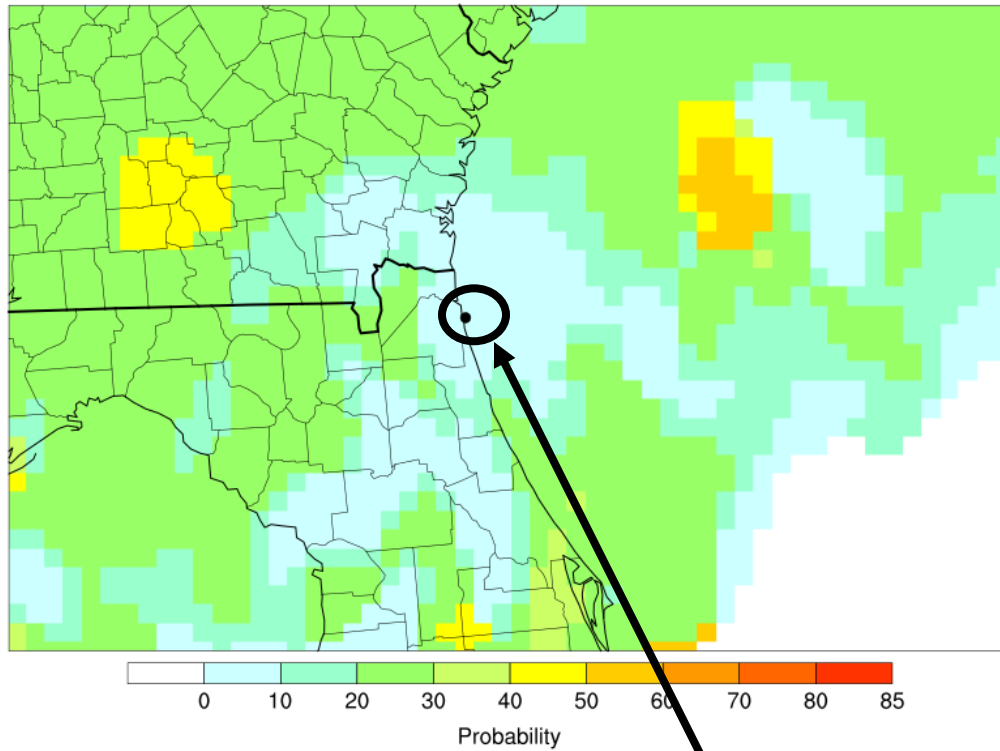


Figure 25 – (top) FIP probability of icing at 21,000 ft msl and (bottom) FIP severity of icing at 21,000 ft msl 1-hour forecast valid for 0900 EST

ICING PROBABILITY at FL 230 01 Hour forecast valid at: 12/20/2018 1400 UTC



ICING SEVERITY at FL 230 01 Hour forecast valid at: 12/20/2018 1400 UTC

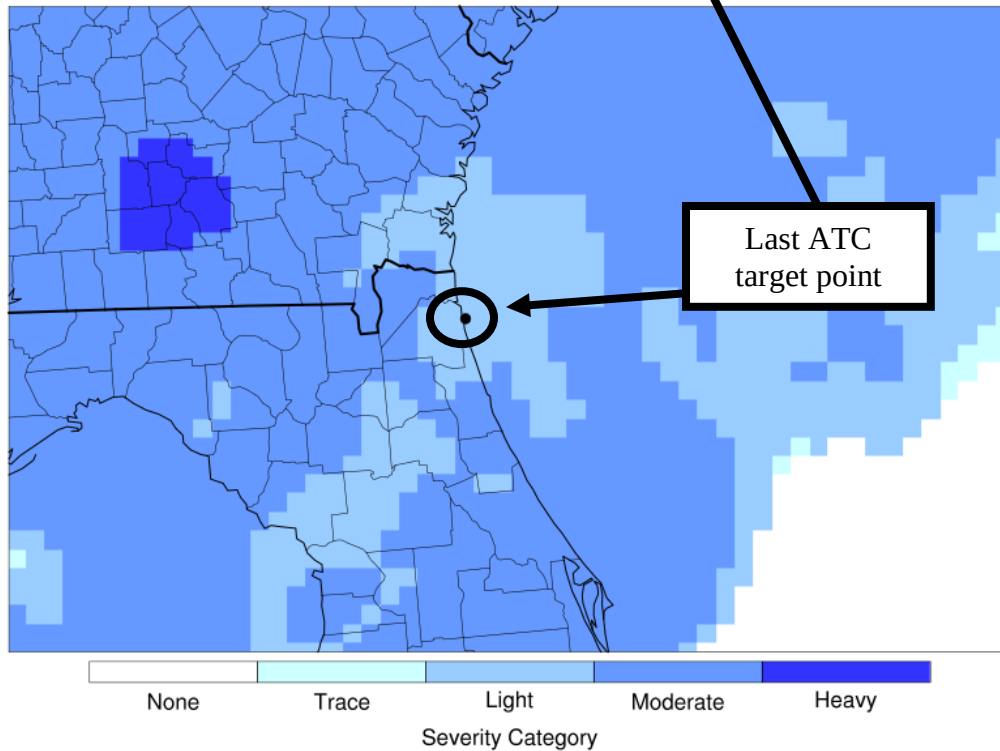


Figure 26 – (top) FIP probability of icing at 23,000 ft msl and (bottom) FIP severity of icing at 23,000 ft msl 1-hour forecast valid for 0900 EST

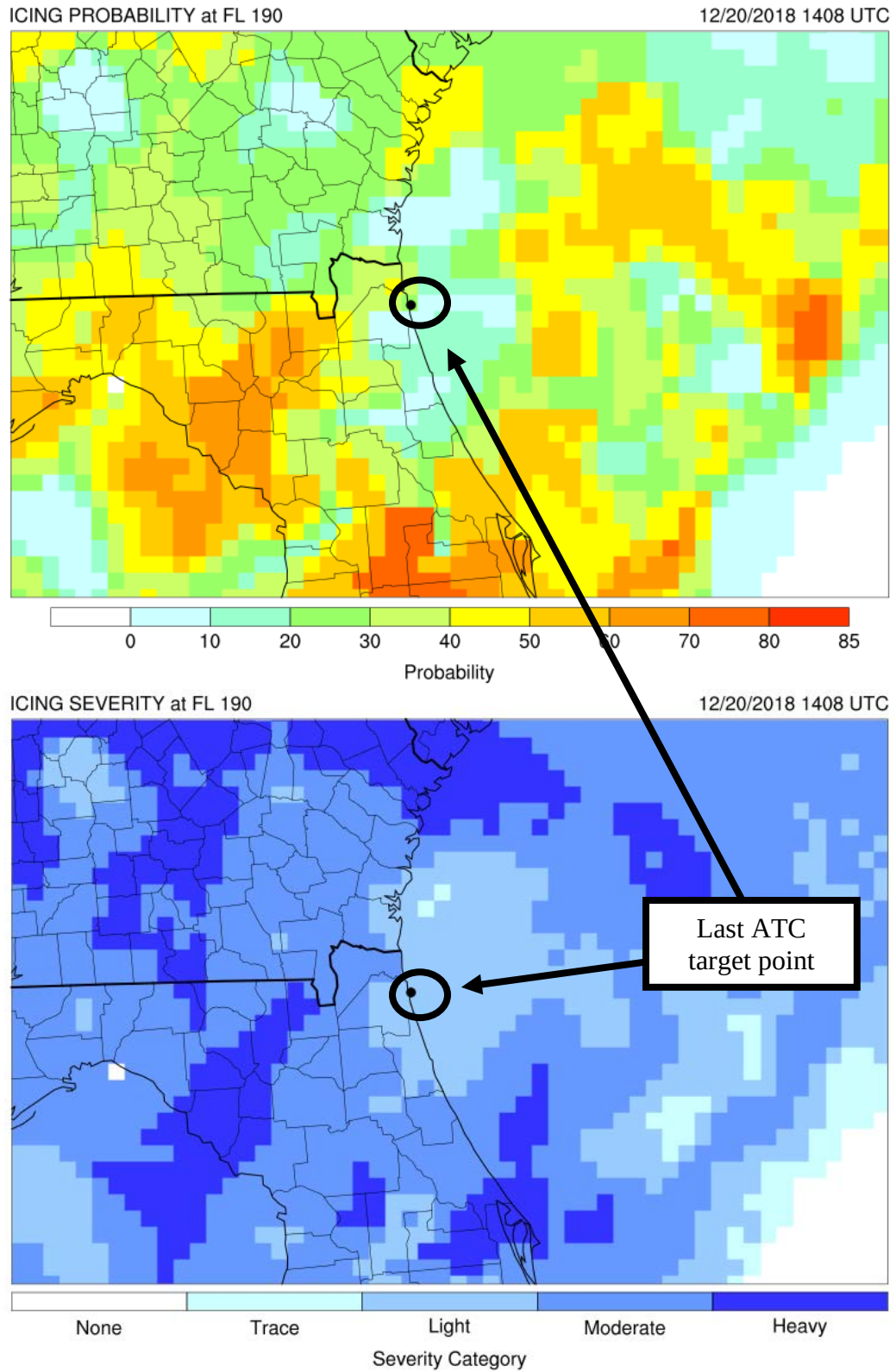
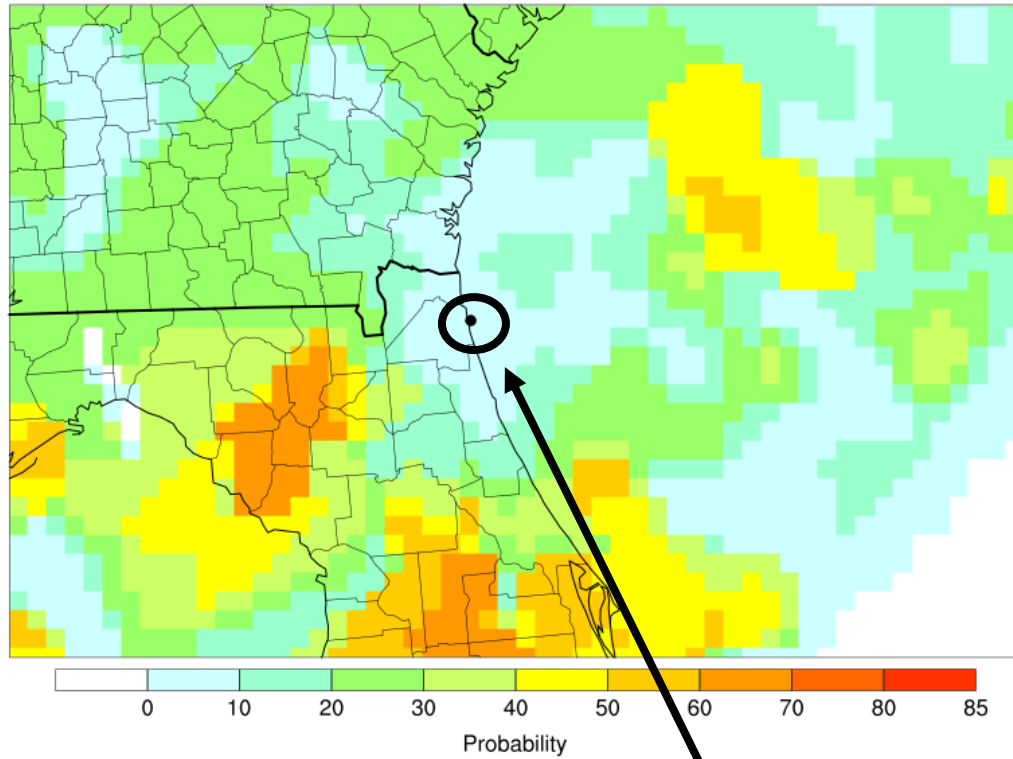


Figure 27 – (top) CIP probability of icing at 19,000 ft msl and (bottom) CIP severity of icing at 19,000 ft msl valid for 0900 EST

ICING PROBABILITY at FL 210 12/20/2018 1408 UTC



ICING SEVERITY at FL 210 12/20/2018 1408 UTC

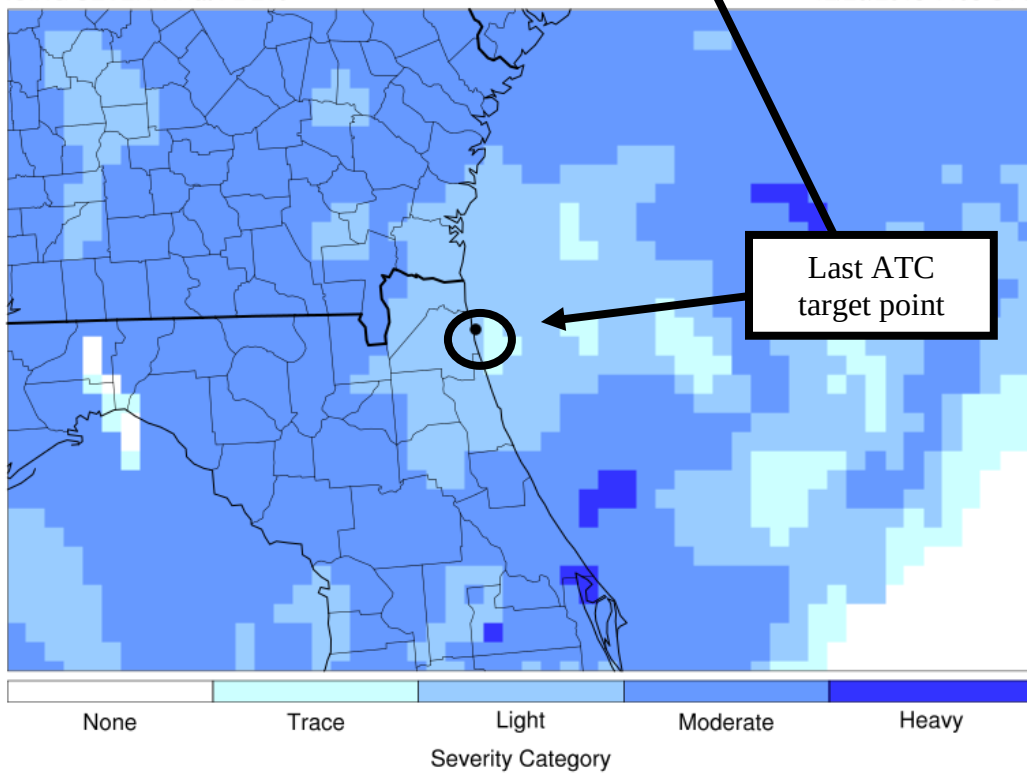
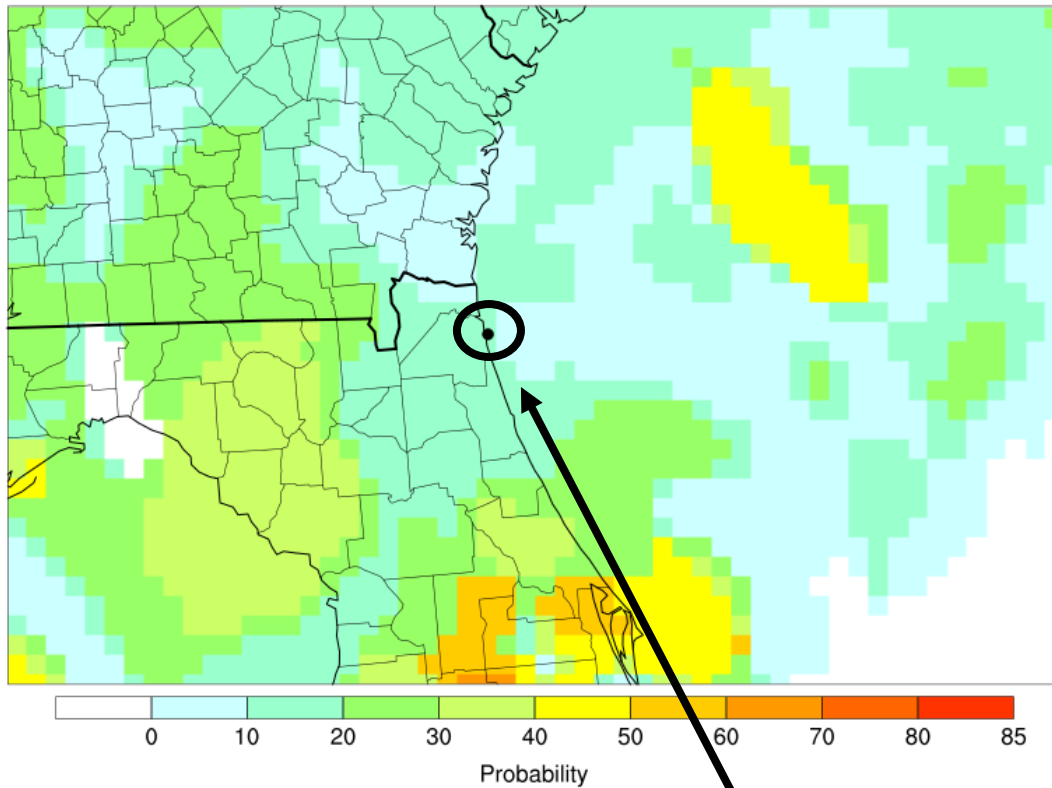


Figure 28 – (top) CIP probability of icing at 21,000 ft msl and (bottom) CIP severity of icing at 21,000 ft msl valid for 0900 EST

ICING PROBABILITY at FL 230

12/20/2018 1408 UTC



ICING SEVERITY at FL 230

12/20/2018 1408 UTC

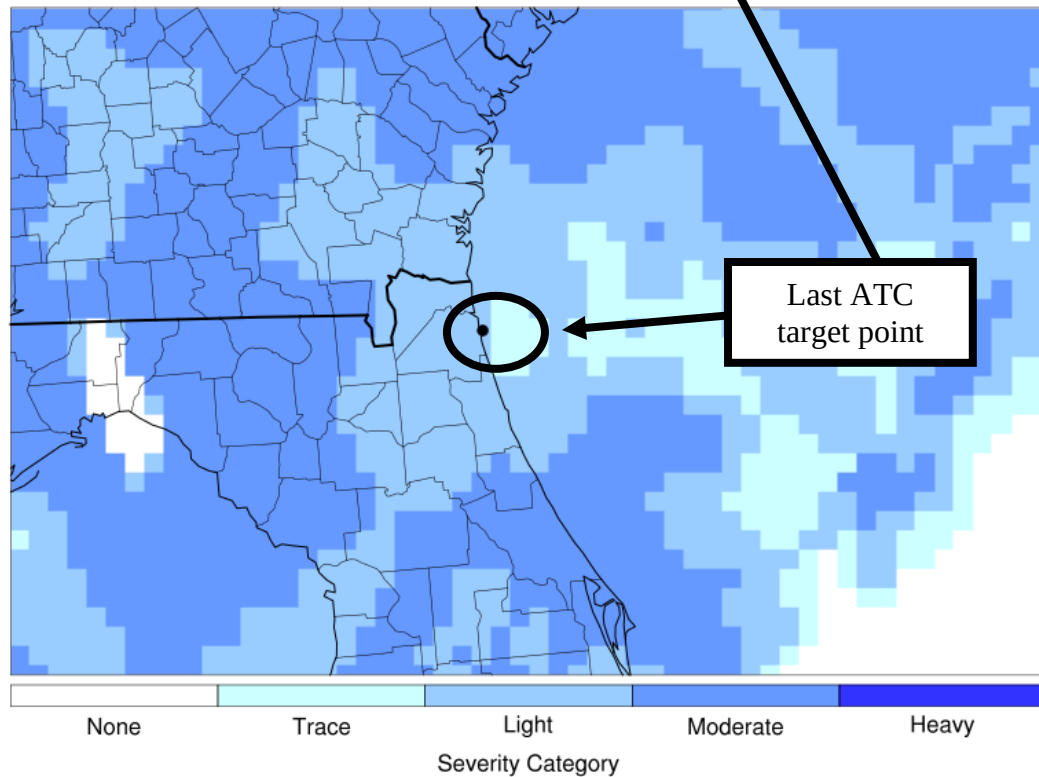


Figure 29 – (top) CIP probability of icing at 23,000 ft msl and (bottom) CIP severity of icing at 23,000 ft msl valid for 0900 EST

20.0 XM Weather images

The airplane was equipped with a Garmin³⁴, which could be optionally fitted to be able to display XM Weather information with a subscription. If the accident pilot had been viewing XM Weather composite radar information he would have had a chance to view something similar to figures 30 through 34 (time in figures in CST), which was XM Weather composite radar information available around and before the accident time. The scale used in the XM Weather composite radar information is located in figure 35. There was an unknown time delay of the XM weather composite images made available in the cockpit.³⁵ The XM Weather composite radar images from 0849 through 0909 EST displayed 20 to 40 dBZ values above the last ATC target point. For additional information regarding the XM Weather composite radar data please see attachment 14.

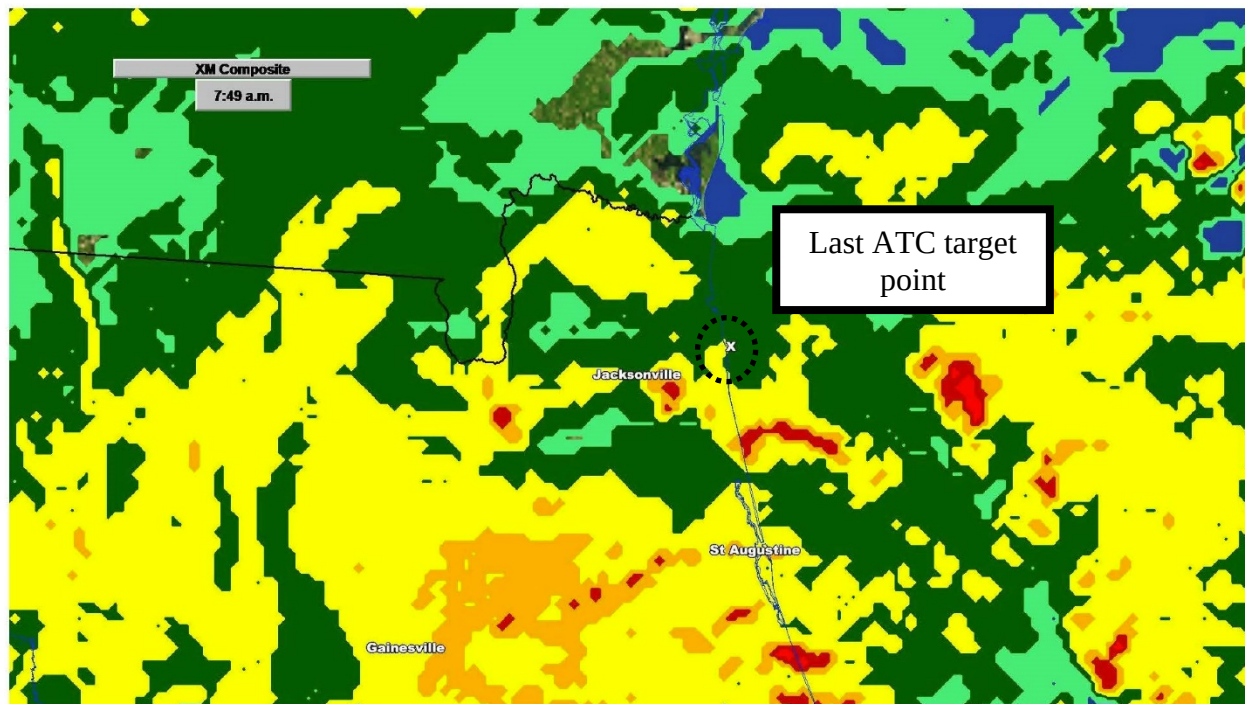


Figure 30 –XM Weather Radar from 0849 EST

³⁴ For more information on the electronic equipment located on the accident aircraft please see the docket information for this accident.

³⁵ See: https://nts.gov/safety/safety-alerts/Documents/SA_017.pdf

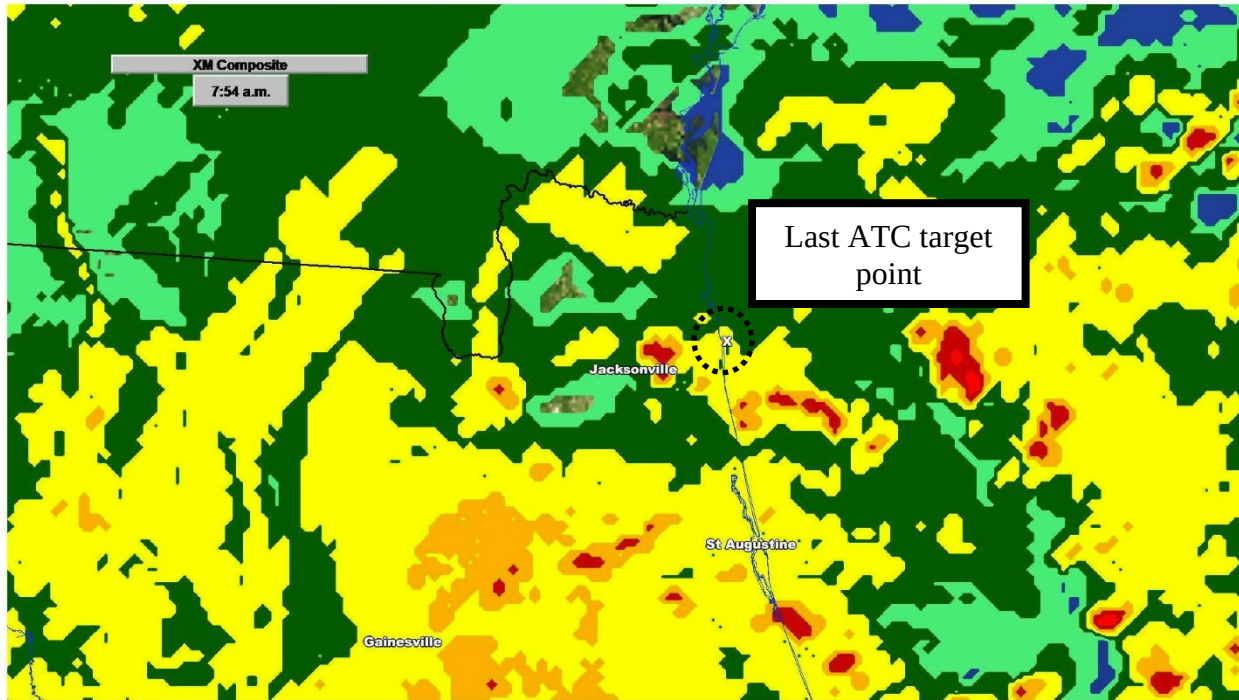


Figure 31 – XM Weather Radar from 0854 EST

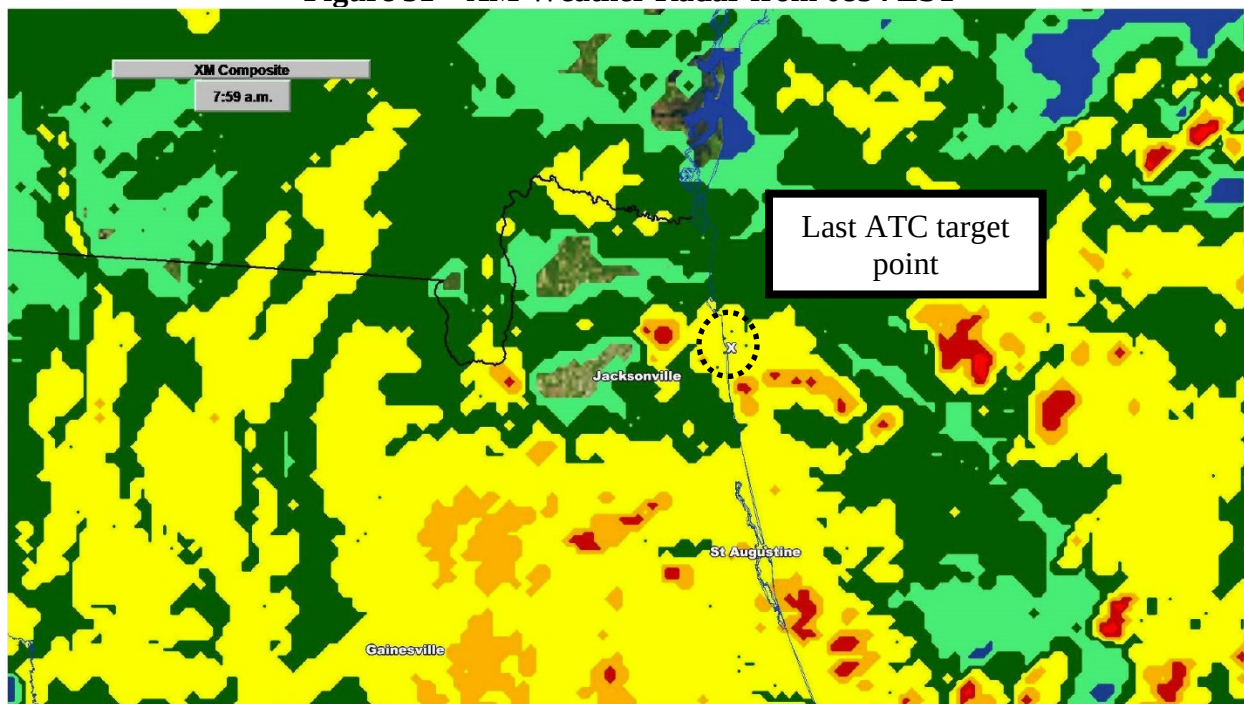


Figure 32 – XM Weather Radar from 0859 EST

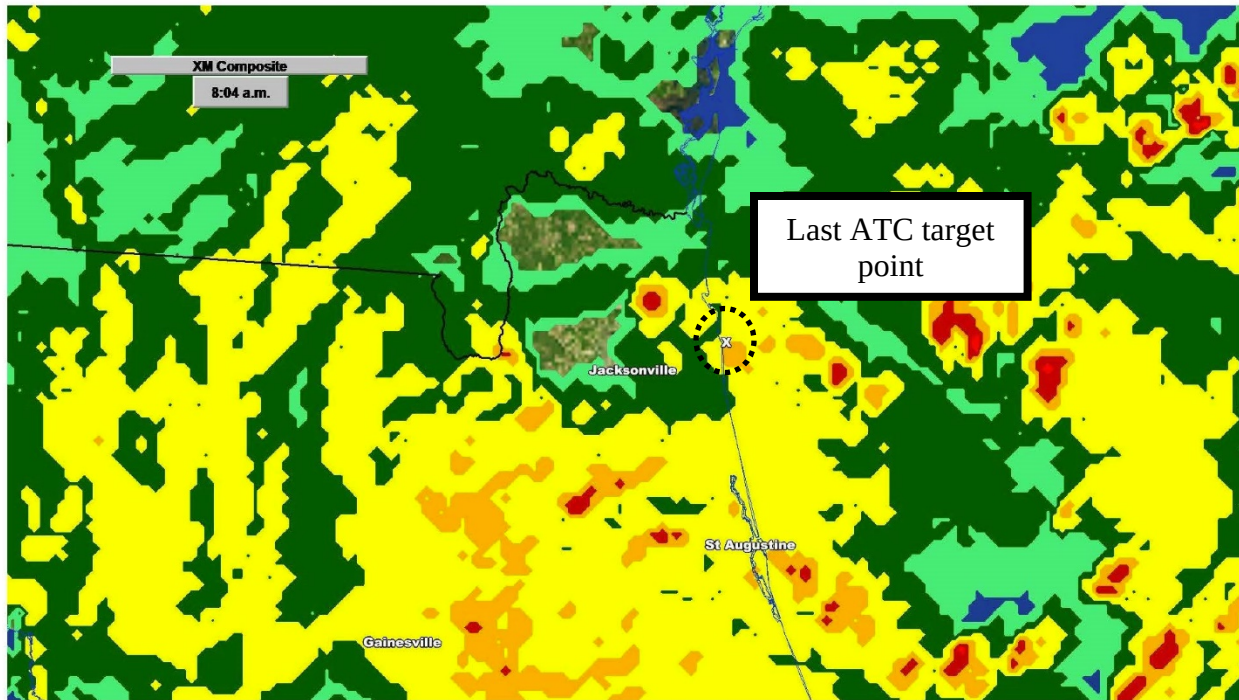


Figure 33 – XM Weather Radar from 0904 EST

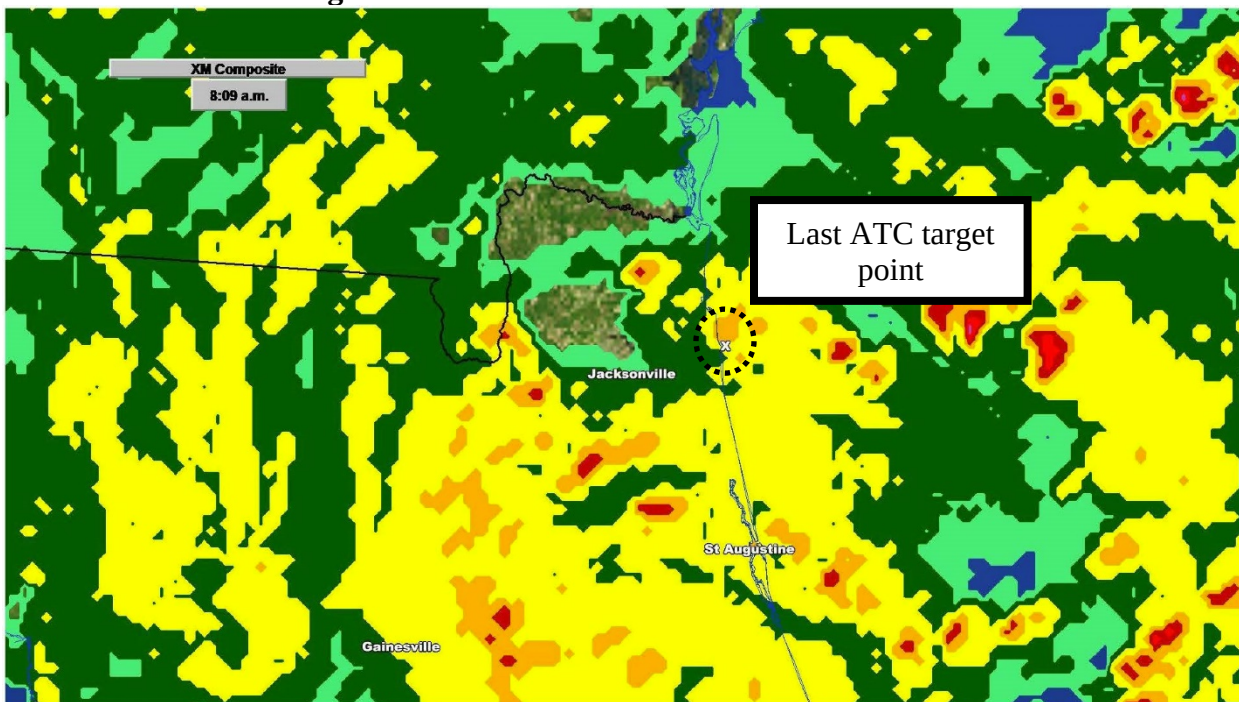


Figure 34 – XM Weather Radar from 0909 EST

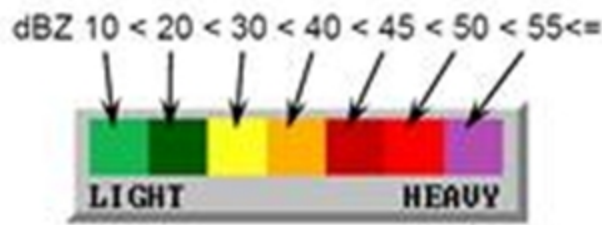


Figure 35 – XM Weather Radar scale for figures 30 through 34

21.0 Advisory Circular 91-74B

FAA Advisory Circular 91-74B published October 8, 2015, provides a reference guide on the principal factors related to flight in icing conditions. Icing in cumulus clouds is discussed on pages 11 and 34, and icing in cumulus clouds can be dangerous due to the higher liquid water content (than liquid water content in stratiform cloud cover). For additional information on flight in icing conditions please see attachment 15.

22.0 Astronomical Data

The astronomical data obtained from the United States Naval Observatory for the accident site on December 20, 2018, indicated the following:

SUN

Begin civil twilight	0651 EST
Sunrise	0718 EST
Accident time	0904 EST³⁶
Sun transit	1223 EST
Sunset	1729 EST
End civil twilight	1755 EST

E. LIST OF ATTACHMENTS

Attachment 1 – GOES-16 Visible animation from 0802 to 1007 EST

Attachment 2 – GOES-16 Infrared animation from 0802 to 1007 EST

Attachment 3 – KJAX WSR-88D level 2 base reflectivity animation for the 12.5° elevation scans from 0830 to 0914 EST

Attachment 4 – KVAX WSR-88D level 3 base reflectivity animation for the 1.3° elevation scans from 0833 to 0920 EST

³⁶ Inserted accident time for reference and context.

Attachment 5 – KVAX WSR-88D level 3 CC animation for the 1.3° elevation scans from 0833 to 0920 EST

Attachment 6 – KVAX WSR-88D level 3 Zdr animation for the 1.3° elevation scans from 0833 to 0920 EST

Attachment 7 – GFA products valid for the accident flight

Attachment 8 – Leidos documentation of ForeFlight weather briefing from 0717 EST

Attachment 9 – Leidos documentation of ForeFlight weather briefing from 0717 EST second copy

Attachment 10 – Leidos documentation of accident flight plan information

Attachment 11 – ForeFlight weather briefing information requested by accident pilot at 0717 EST

Attachment 12 – CWSU ZJX pre-duty weather briefing

Attachment 13 – CIP and FIP products valid at 0800 and 0900 EST for the accident flight

Attachment 14 – XM weather composite weather radar imagery from around accident time

Attachment 15 – FAA AC 91-74B

Attachment 16 – CIP and FIP products valid 0900 EST but available at the time of weather briefing

Submitted by:

Paul Suffern
Senior Meteorologist

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