



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

April 2, 2020

Weather Study

METEOROLOGY

DCA20CA071

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A. ACCIDENT

Location: Knoxville, Tennessee
Date: February 7, 2020
Time: 0105 eastern standard time
0605 Universal Coordinated Time (UTC)
Aircraft: PSA Airlines flight 5634, Canadair CRJ900; Registration: N610NN

B. METEOROLOGIST

Donald Eick
Meteorology Specialist
Operational Factors Division (AS-30)
National Transportation Safety Board

C. SUMMARY

On February 7, 2020, about 0105 eastern standard time, PSA Airlines flight 5634, a Canadair CRJ-900, N610NN encountered turbulence while descending to land. One flight attendant and 21 passengers sustained minor injuries. One flight attendant sustained serious injuries, and the airplane sustained minor damage. The regularly scheduled domestic passenger flight was operating under the provisions of 14 *Code of Federal Regulations* Part 121 from Charlotte Douglas International Airport (KCLT), North Carolina, to McGhee Tyson Airport (KTYS), Knoxville, Tennessee.

D. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's Senior Meteorologist was not on scene for this investigation and conducted the meteorology phase of the investigation from the Washington D.C. office, collecting data from official National Weather Service (NWS) sources including the Weather Prediction Center (WPC) and the National Center for Environmental Information (NCEI). All times are eastern standard time (EST) based upon the 24-hour clock, local time is -5 hours from UTC, and UTC=Z. NWS airport and station identifiers use the standard International Civil Aviation Organization 4-letter station identifiers versus the International Air Transport Association 3-letter identifiers, which deletes the initial country code designator "K" for U.S. airports. Directions are referenced to true north and distances in nautical miles. Heights are in feet (ft) above mean sea level (msl) unless otherwise noted. Visibility is in statute miles and fractions of statute miles.

The turbulence location was determined from the flight data recorder (FDR) data to be at latitude 35.3525869° N and longitude 83.0216217° W as the flight was descending through approximately 20,000 ft.

E. WEATHER INFORMATION

1.0 Synoptic Conditions

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 (NCEP) and the Weather Prediction Center (WPC) located in College Park, Maryland. These are the base products used in describing weather features and in the creation of forecasts and warnings. Reference to these charts can be found in the joint NWS and Federal Aviation Administration (FAA) Advisory Circular “Aviation Weather Services”, AC 00-45H change 2.

1.1 Surface Analysis Chart

The eastern-central section of the NWS high-resolution Surface Analysis Chart for 0100 EST on February 7, 2020 is included as figure 1 with the approximate turbulence encounter location noted by a red star and the destination of Knoxville, Tennessee, located within the red circle. The chart depicted a low-pressure system at 989-hectopascals (hPa)¹ over western North Carolina to the northeast of the turbulence location with a cold front extending southward across western North Carolina and South Carolina, into Georgia and the Florida Panhandle. North of the low a stationary front extended from eastern Tennessee, northward into western Virginia and into West Virginia. To the east, another stationary front was located along the North Carolina coast with a low pressure system of 993-hPa immediately off the South Carolina coasts. A squall line² extended immediately south of this low off the South Carolina and Georgia coast and extended south-southwest into central Florida. The turbulence encounter occurred to the southwest of the main low-pressure system and behind the cold front, in the cold air sector of the front. The squall line was located to the east of the departure airport and did not impact the route.

¹ Hectopascals is the new NWS reference for reporting sea level pressure and is interchangeable with the former term millibar (mb) with the same units. Standard sea-level pressure is 1013.25-hPa at 59° Fahrenheit (F) or 15° Celsius (C).

² Squall Line – is a line of active cumulonimbus clouds or thunderstorms, either continuous or with breaks, and typically forms along or ahead of cold fronts and often produce severe weather.

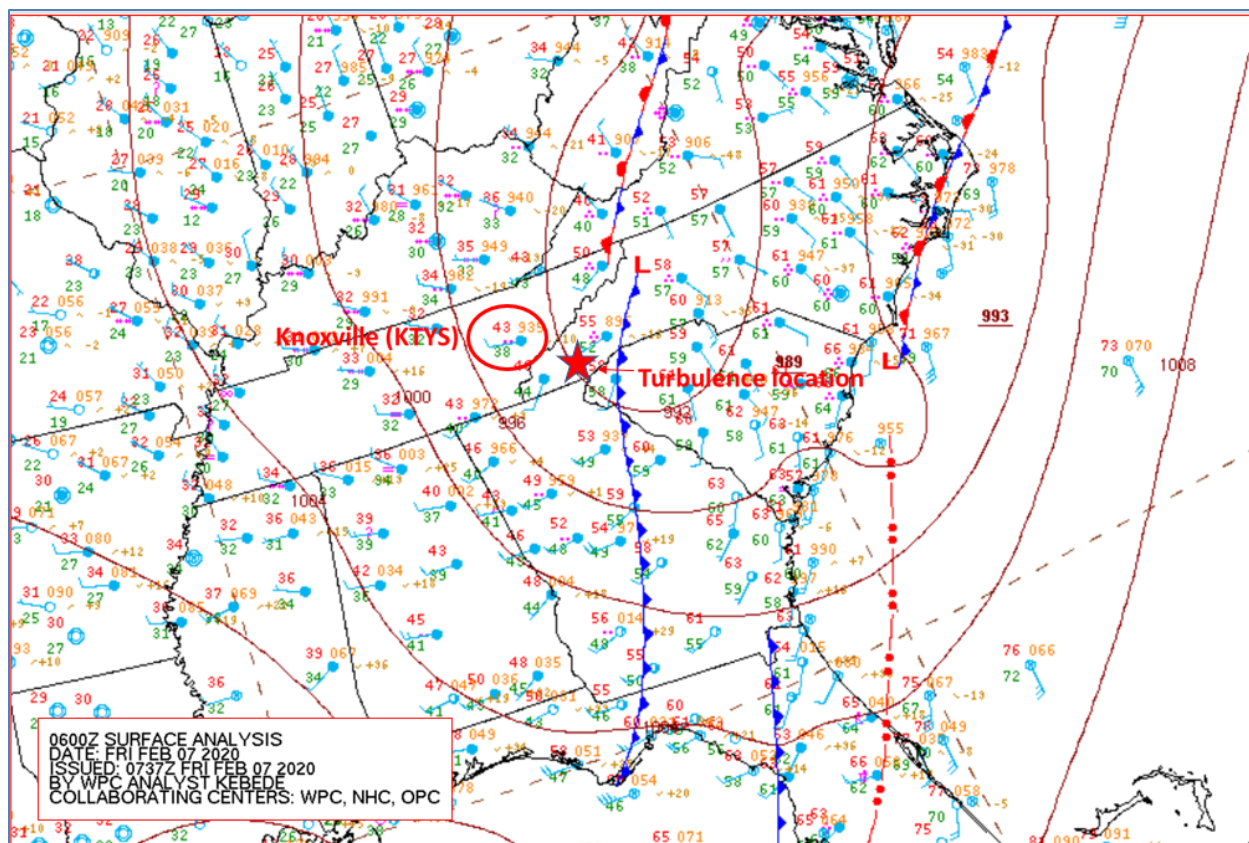


Figure 1 - Section of the high-resolution Surface Analysis Chart for 0100 EST with turbulence location marked

The station models in the vicinity of the turbulence encounter depicted surface winds from the northwest to westerly winds of 5 to 10 knots, overcast sky cover, with visibility restricted in light to heavy rain, and with temperatures in the 40's to mid 50's °F.

1.2 National Composite Radar Mosaic

The NWS National Composite Radar Mosaic for 0100 EST for the east-central United States is included as figure 2 with the approximate turbulence encounter location marked by the red star. The radar mosaic depicted a defined band of strong echoes extending off the South Carolina coast south-southwestward into central Florida, which was associated with a squall line. In the immediate vicinity of the turbulence encounter several short northeast-to-southwest bands of echoes were noted. Figure 3 is a close-up of the echoes in the immediate vicinity of the turbulence encounter for 0105 EST, which depicted several northeast-to-southwest bands of echoes with reflectivity's of 30 to 50 dBZ.

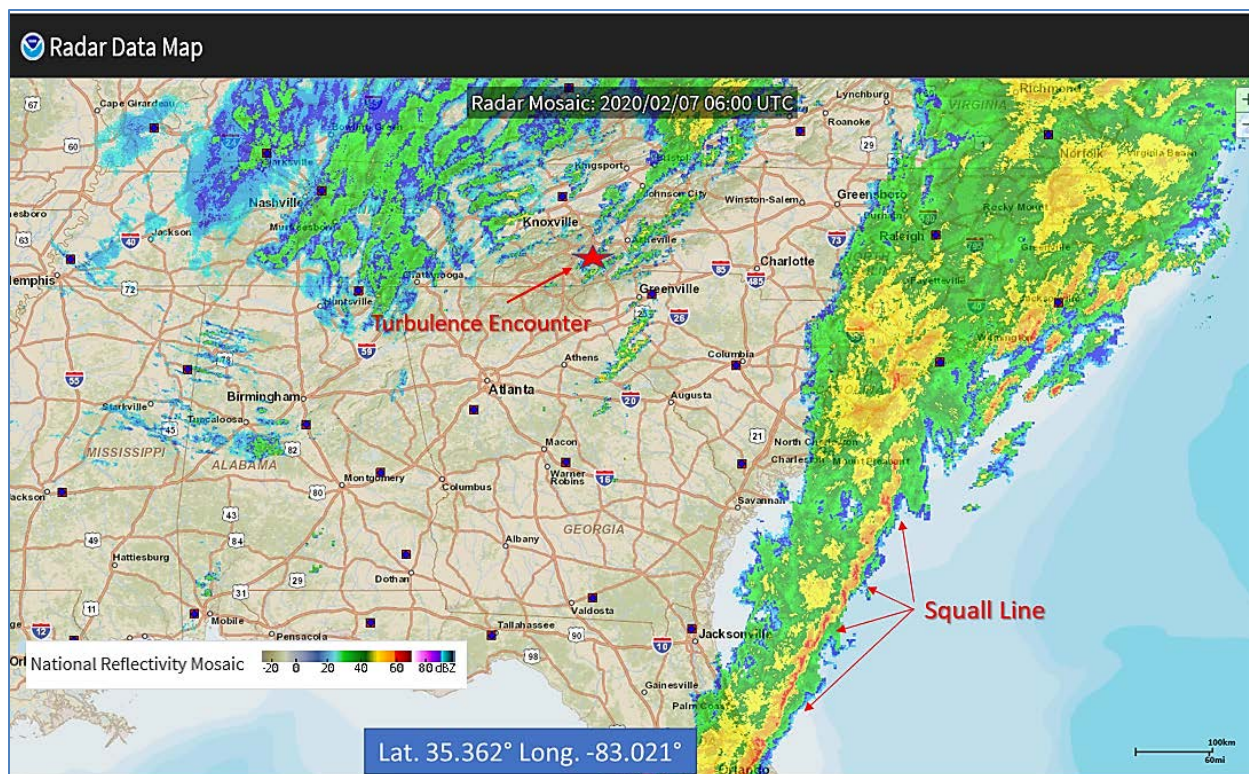


Figure 2 - NCEI National Composite Radar Mosaic for 0100 EST



Figure 3 - Close-up of the National Composite Radar Mosaic for 0105 EST

Based on the potential for echoes along the flight path, the closest NWS weather surveillance radar is further documented in section 5.0 of this report.

1.3 Convective Outlook

The NWS Storm Prediction Center (SPC) is tasked with providing timely and accurate forecasts and watches for severe thunderstorms and tornadoes over the contiguous United States. One of their primary products highlighting the expected areas of organized thunderstorms is the Convective Outlook (AC), which is often used in pilot preflight weather briefings and referenced in inflight weather advisories. The intent of the chart is to identify to users like NWS forecasters, emergency managers, media, and pilots where the NWS SPC expects organized thunderstorms and severe thunderstorms³ to form.

Figure 4 depicts the last NWS SPC Convective Outlook issued the evening of February 6th that was current for the overnight period, which discussed where the main concern for thunderstorms were for the following 24-hour period. The chart depicted a slight risk of severe thunderstorms over eastern North Carolina and South Carolina, southeast Georgia, and over Florida during the period. No organized thunderstorms were expected over the proposed route of flight or where the turbulence encounter occurred.

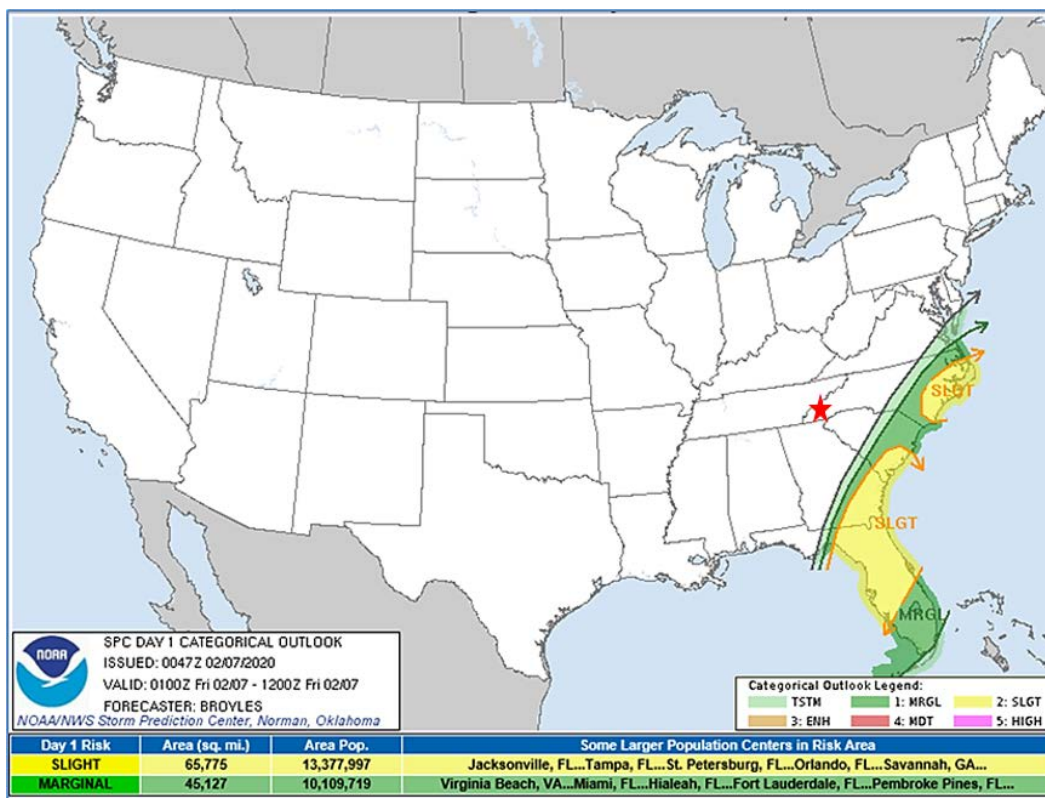


Figure 4 - NWS Convective Outlook valid for the period

³ A severe thunderstorm is one that produces a tornado, large hail over 1.0 inch in diameter, or outflow winds greater than 50 knots. While all thunderstorms imply the likelihood of severe turbulence, a severe thunderstorm implies a high likelihood of severe to extreme turbulence, wind shear, and a high probability of encountering hail.

1.4 Upper Air Charts

The NWS Constant Pressure Charts obtained from the University of Wyoming archive data for 1900 EST on February 6th (0000Z on February 7th) for 850-, 700-, 500-, 300-hPa are included as figures 5-8 with the approximate turbulence encounter location marked by a red star. The charts depicted the height contours, isotherms⁴, and isotachs⁵ on the 300-hPa chart, and the station observation of wind direction and speed, temperature, temperature-dew point spread (or dew point depression), and height of the pressure surface in meters. The long and short wave upper level troughs and the 0° C isotherm (or freezing level) have been annotated for reference.

Figure 5 is the 850-hPa constant pressure chart representing the conditions at approximately 5,000 ft. The chart depicted a defined long wave trough extending from Lake Erie southwestward into Louisiana and a short wave trough immediately west of the turbulence encounter running north-to-south over eastern Tennessee and Georgia. The 0° C isotherm highlighted in red depicted the freezing level near 5,000 ft across central Tennessee. The isotherms were perpendicular to the contour lines over the region and indicated cold air advection⁶. The station models surrounding the turbulence encounter depicted southwest winds of 10 to 30 knots, with temperatures between 5° and 10° C, with temperature-dew point spreads of less than 2° C.

The 700-hPa constant pressure chart (figure 6) depicted the conditions at about 10,000 ft and depicted the long wave trough extending from Lake Michigan southwestward into Louisiana. The 0° C isotherm was over the approximate turbulence location and also depicted cold air advection. The station models surrounding the area indicated southwest winds of 40 to 65 knots at that level.

The 500-hPa chart (figure 7) depicted the conditions at about 18,000 ft or the mean atmosphere, and which was immediately below the turbulence encounter. The chart depicted the long wave trough extending from Iowa southward into eastern Texas, with the turbulence location near the inflection point between the base of the trough and the ridge in an area favorable for rising air and conditions favorable for clouds and precipitation. The station models surrounding the area depicted winds from the south-southwest from 75 knots upstream and to 110 knots located downstream over Atlanta (FFC).

The 300-hPa constant pressure chart (figure 8) depicted the conditions at approximately 30,000 ft and presented isotachs highlighting the jet stream. The long wave trough was depicted extending from Iowa southward into eastern Texas, with the turbulence location on the front side of the trough and within the boundaries of a jet stream with winds from the south at 110 to 140 knots with a maximum wind further west over Nashville (BNA) of 170 knots.

⁴ Isotherm – is a line connecting points of equal temperature and usually draw at 5° C intervals.

⁵ Isotach – is a line connecting points of equal wind speed and usually are draw every 20 knots and shaded over 70 knots to depict the boundary of the jet stream.

⁶ Cold advection is the process in which the wind blows from a region of cold air to a region of warmer air.

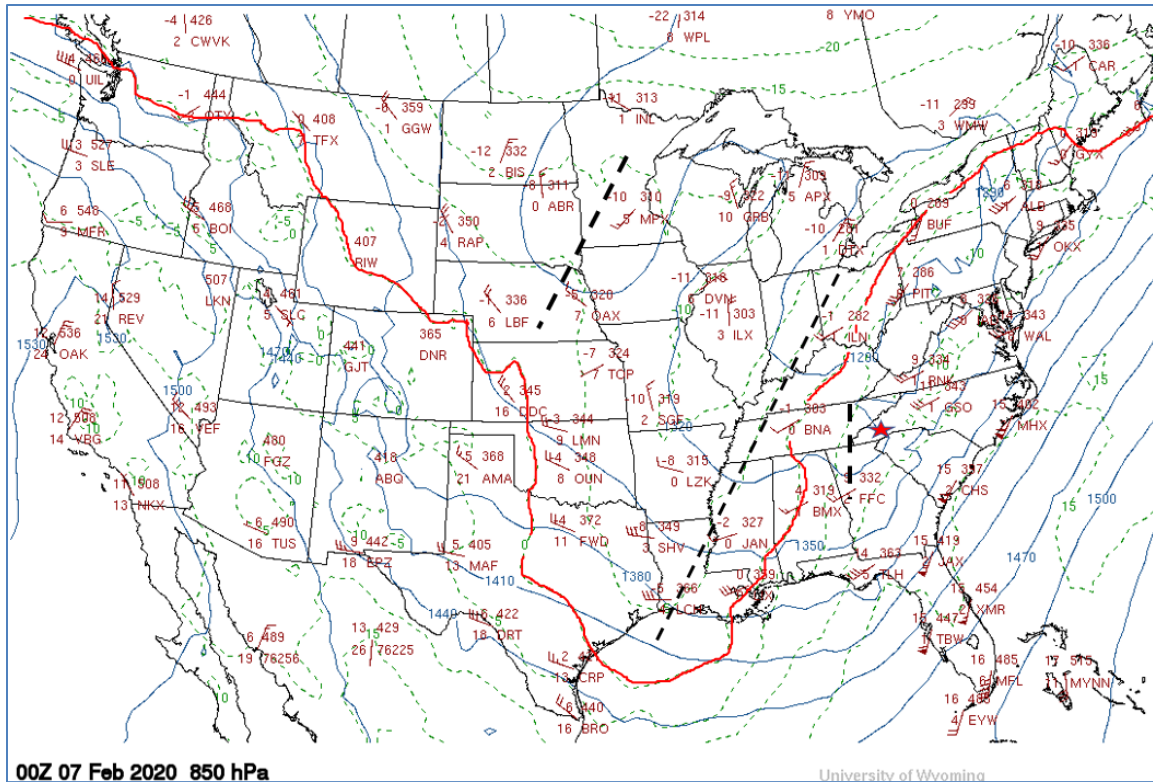


Figure 5 – NWS 850-hPa Constant Pressure chart for 1900 EST

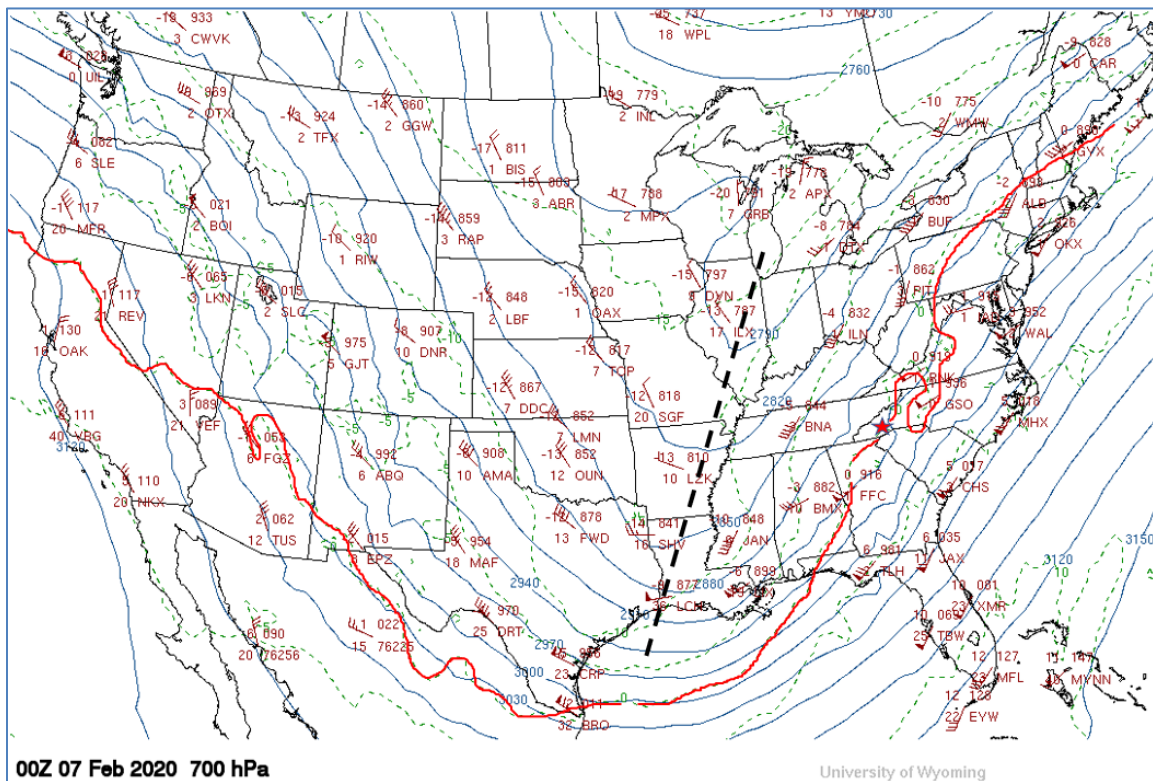


Figure 6 – NWS 700-hPa Constant Pressure chart for 1900 EST

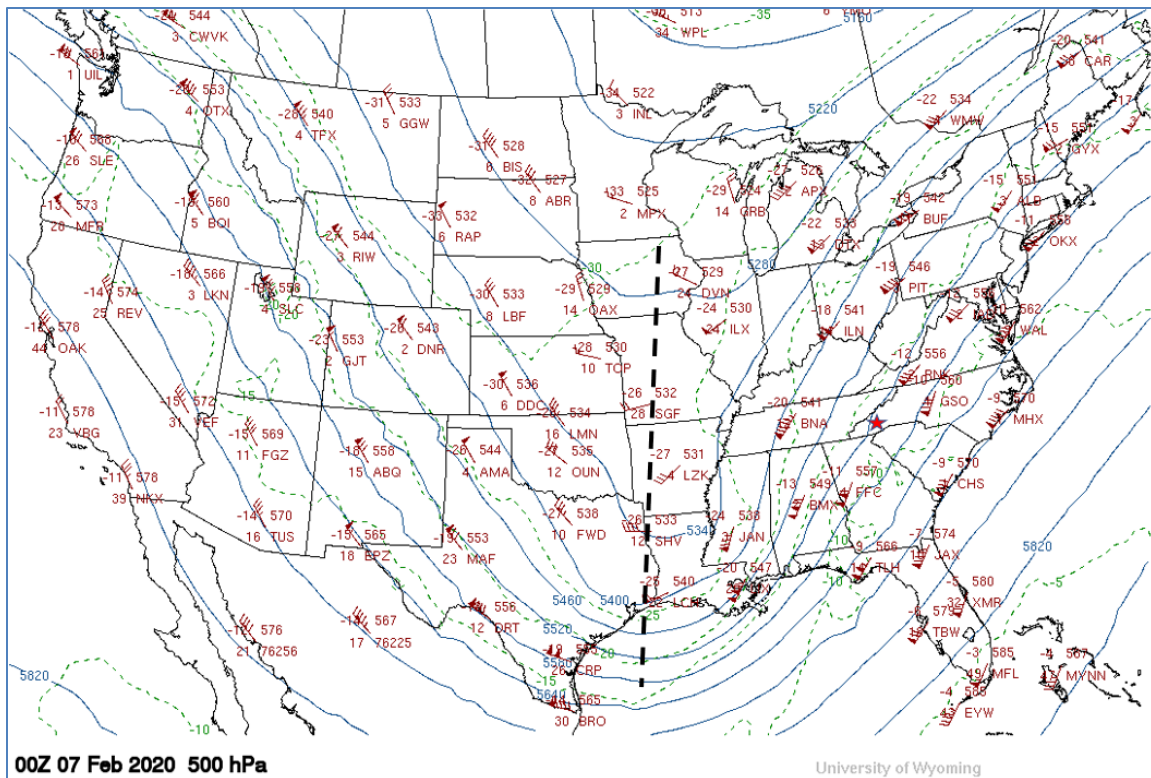


Figure 7 - NWS 500-hPa Constant Pressure chart for 1900 EST

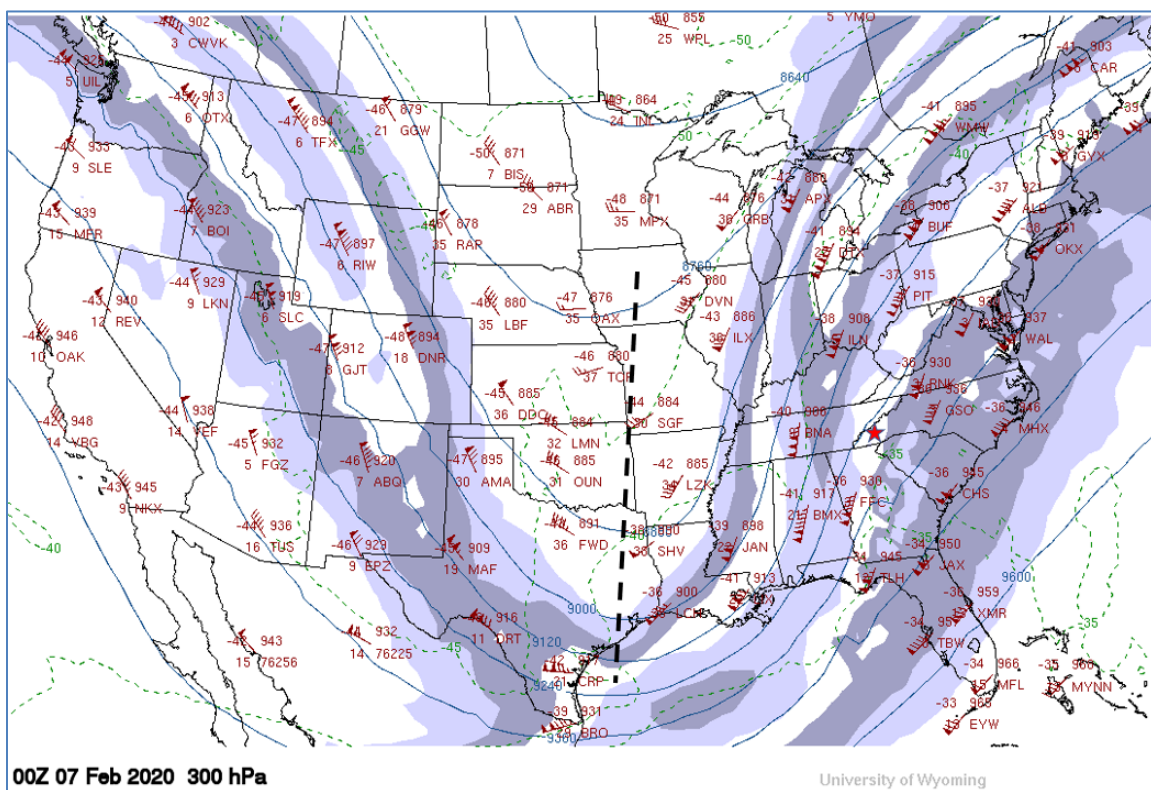


Figure 8 - NWS 300-hPa Constant Pressure chart for 1900 EST

2.0 Surface Observations

The official observations issued surrounding the turbulence site were documented using standard meteorological aerodrome reports (METARs) and specials (SPECI). Cloud heights are reported above ground level (agl) in the following section, and the magnetic variation was estimated at 5° west based on the latest sectional chart for the area.

2.1 Sylva, North Carolina

The closest weather reporting location was Jackson County Airport (K24A), Sylva, North Carolina, located approximately 10 miles west-southwest from the turbulence encounter at an elevation of 2,857 ft. The airport had an Automated Weather Observation System (AWOS), which was not augmented by any human observers and issued observations every 20-minutes. The following conditions were reported surrounding the time of the turbulence event.

Weather observation for K24A at 0055 EST, automated, wind from 240° at 8 knots, visibility 10 miles or more in light rain, ceiling broken at 1,600 ft agl, broken at 2,000 ft, overcast at 3,100 ft, temperature 10° Celsius (C), dew point temperature 8° C, altimeter 29.28 inches of mercury (Hg). Remarks: automated station with a precipitation discriminator, temperature 10.3° C, dew point 8.5° C, 6-hour maximum temperature 12.6° C, 6-hour minimum temperature 10.2° C, 6-hour precipitation total 0.03 inches.

Weather observation for K24A at 0115 EST, automated, wind from 230° at 9 knots gusting to 17 knots, wind 190° variable 260°, visibility 10 miles or more, ceiling broken at 1,700 ft agl, overcast at 2,400 ft, temperature 10° C, dew point temperature 8° C, altimeter 29.28 inches of Hg. Remarks: automated station with a precipitation discriminator, temperature 9.8° C, dew point 7.5° C.

The general flight categories⁷ and raw observations from approximately 2200 through 0330 EST were as follows. The observation decoded above and the time of the event are in bold italic print for reference.

VFR ***METAR K24A 070255Z AUTO 18003KT 10SM OVC110 11/10 A2933 RMK AO2 LTG DSNT SE T01110103 60001=***
VFR ***METAR K24A 070315Z AUTO 00000KT 10SM SCT034 SCT060 OVC110 11/10 A2932 RMK AO2 T01130103=***
VFR ***METAR K24A 070335Z AUTO 18010KT 10SM -RA SCT024 BKN060 OVC090 11/10 A2932 RMK AO2 LTG DSNT SE T01140101=***

⁷ As defined by the NWS and the FAA Aeronautical Information Manual (AIM) section 7-1-7 defines the following general flight categories based on weather conditions reported:

- Low Instrument Flight Rules (LIFR*) – ceiling below 500 ft above ground level (agl) and/or visibility less than 1 statute mile.
- Instrument Flight Rules (IFR) – ceiling between 500 to below 1,000 feet agl and/or visibility 1 to less than 3 miles.
- Marginal Visual Flight Rules (MVFR**) – ceiling from 1,000 to 3,000 ft agl and/or visibility 3 to 5 miles.
- Visual Flight Rules (VFR) – ceiling greater 3,000 ft agl and visibility greater than 5 miles.

* By definition, IFR is a ceiling less than 1,000 ft agl and/or visibility less than 3 miles while LIFR is a sub-category of IFR.

**By definition, VFR is a ceiling greater than or equal to 3,000 ft agl and visibility greater than 5 miles while MVFR is a sub-category of VFR.

VFR METAR K24A 070355Z AUTO 21011KT 10SM -RA SCT042 BKN055 OVC090 12/09 A2932 RMK AO2 T01170094=

VFR METAR K24A 070415Z AUTO 20006KT 7SM -RA BR BKN055 OVC070 11/09 A2929 RMK AO2 P0002 T01120088=

VFR METAR K24A 070435Z AUTO 21007G16KT 10SM -RA SCT038 BKN060 OVC100 12/09 A2930 RMK AO2 LTG DSNT SE P0002 T01180092=

MVFR METAR K24A 070455Z AUTO 21005KT 10SM BKN026 BKN032 OVC080 12/09 A2926 RMK AO2 P0002 T01170091=

MVFR METAR K24A 070515Z AUTO 24006KT 10SM BKN021 OVC027 11/09 A2928 RMK AO2 T01120093=

MVFR METAR K24A 070535Z AUTO 24008G15KT 200V260 10SM BKN016 BKN022 OVC027 11/09 A2928 RMK AO2 T01090091=

MVFR METAR K24A 070555Z AUTO 24008KT 10SM -RA BKN016 BKN020 OVC031 10/08 A2928 RMK AO2 T01030085 10126 20102 60003=

Turbulence encounter 0605Z

MVFR METAR K24A 070615Z AUTO 23009G17KT 190V260 10SM BKN017 OVC024 10/08 A2928 RMK AO2 T00980075=

MVFR METAR K24A 070635Z AUTO 23009G19KT 190V270 10SM -RA BKN017 OVC024 09/07 A2927 RMK AO2 T00930069=

MVFR METAR K24A 070655Z AUTO 25013G24KT 210V270 10SM -RA BKN019 BKN033 OVC060 08/06 A2928 RMK AO2 T00840059=

VFR METAR K24A 070715Z AUTO 23012G19KT 10SM SCT025 BKN050 OVC070 08/05 A2927 RMK AO2 T00830047=

VFR METAR K24A 070735Z AUTO 23017G26KT 10SM SCT030 BKN039 OVC060 08/04 A2928 RMK AO2 T00790037=

VFR METAR K24A 070755Z AUTO 23011G19KT 10SM SCT025 BKN034 OVC044 07/03 A2928 RMK AO2 T00720033=

MVFR METAR K24A 070815Z AUTO 25008KT 190V270 10SM -RA BKN026 BKN036 OVC044 07/03 A2929 RMK AO2 LTG DSNT NE T00650033=

A review of the observations indicated that MVFR conditions prevailed at K24A at the time of the turbulence encounter with overcast clouds and a band of rain moving through the station. While no thunderstorms were reported during the period there were numerous reports of lightning in the distance or beyond 10 miles of the station between 2300 and 0330 EST.

2.2 Asheville, North Carolina

The next closest reporting station was from Asheville Regional Airport (KAVL), Asheville, North Carolina, located approximately 24 miles east-northeast from the turbulence encounter at an elevation of 2,162 ft. The airport had a federally installed and maintained Automated Surface Observation System (ASOS) which was augmented by air traffic control personnel during normal hour of operations. The following conditions were reported at the approximate time of the turbulence encounter.

Special weather observation for KAVL at 0104 EST, automated, wind from 210° at 8 knots, visibility 1 mile, runway 35 10-minute runway visual range 3,000 ft variable to better than 6,000 ft, light rain and mist, a few clouds at 900 ft agl, scattered clouds at 1,300 ft, ceiling overcast at 2,000 ft, temperature 13° C, dew point 12° C, altimeter 29.25 inches of Hg. Remarks: automated station with a precipitation discriminator, hourly precipitation since 0054 EST 0.24 inches, temperature 12.8° C, dew point 11.7° C.

The general flight categories and raw observations surrounding the turbulence event were as follows.

MVFR METAR KAVL 070254Z 00000KT 3SM RA BR SCT008 BKN017 OVC022 13/12 A2932 RMK AO2 SLP912 P0023 60026 T01330117 58034=
MVFR SPECI KAVL 070312Z 18008KT 3SM -RA BR SCT006 BKN010 OVC016 13/12 A2931 RMK AO2 CIG 008V014 P0005 T01330117=
MVFR SPECI KAVL 070342Z 16006KT 10SM -RA FEW006 OVC017 13/12 A2932 RMK AO2 CIG 010V029 P0007 T01280117=
MVFR METAR KAVL 070354Z AUTO 15005KT 10SM -RA SCT015 BKN021 OVC080 13/12 A2932 RMK AO2 SLP912 P0007 T01280117=
VFR SPECI KAVL 070405Z AUTO 15006KT 9SM -RA FEW017 BKN060 OVC080 13/11 A2932 RMK AO2 P0000 T01280111=
MVFR SPECI KAVL 070440Z AUTO 11004KT 10SM -RA SCT019 BKN029 OVC085 13/11 A2929 RMK AO2 P0001 T01280111=
MVFR METAR KAVL 070454Z AUTO 14005KT 10SM -RA BKN019 BKN026 OVC031 13/11 A2928 RMK AO2 SLP900 P0002 T01280111 401500128=
IFR SPECI KAVL 070550Z AUTO 26008KT 2 1/2SM +RA BR FEW009 BKN018 OVC024 13/11 A2926 RMK AO2 P0004=
IFR METAR KAVL 070554Z AUTO 26007KT 1 3/4SM +RA BR SCT009 OVC019 13/11 A2927 RMK AO2 PRESRR SLP895 P0010 60045 T01280111 10139 20128 58016=
IFR SPECI KAVL 070556Z AUTO VRB04KT 1 1/4SM R35/4000VP6000FT +RA BR FEW009 BKN014 OVC021 13/12 A2925 RMK AO2 P0003 T01280117=
IFR SPECI KAVL 070604Z AUTO 21008KT 1SM R35/3000VP6000FT -RA BR FEW009 SCT013 OVC020 13/12 A2925 RMK AO2 P0024 T01280117=
Turbulence encounter 0605Z
IFR SPECI KAVL 070607Z AUTO 20006KT 2 1/2SM R35/5500VP6000FT -RA BR FEW009 SCT013 OVC020 13/12 A2924 RMK AO2 P0025 T01280117=
MVFR SPECI KAVL 070614Z AUTO 19006KT 10SM -RA FEW008 BKN016 OVC032 13/11 A2922 RMK AO2 PRESFR P0025 T01330111=
VFR METAR KAVL 070654Z AUTO 20015G22KT 10SM SCT022 BKN031 OVC050 13/09 A2922 RMK AO2 RAE51 SLP877 P0025 T01330094=

A review of the observations for KAVL indicated that MVFR to IFR conditions prevailed at the airport during the period with light to heavy rain, with the heaviest period of rain occurring immediately prior to the turbulence event between 0050 and 0104 EST with 0.24 inches of rainfall recorded. The total 24-hour rainfall⁸ reported at 0800 EST after the accident was 2.64 inches. No thunderstorms were reported during the period immediately surrounding the time of the accident.

2.3 Knoxville, Tennessee

The destination airport of McGhee Tyson Airport (KTYN), Knoxville, Tennessee, was located approximately 55 miles west-northwest of the turbulence encounter, at an elevation of 979 ft. The airport had a federally installed and maintained ASOS which was also augmented by air traffic control personnel. The following conditions were reported at the time of the turbulence encounter.

Weather observation for KTYN at 0053 EST, wind from 280° at 9 knots, visibility 10 miles or more in light rain, scattered clouds at 1,200 ft agl, ceiling overcast at 2,800 ft, temperature 6° C, dew point 3° C, altimeter 29.35 inches of Hg. Remarks: automated station with a precipitation

⁸ The 24-hour rainfall report is typically reported on the 12Z observation, which was not included in the reports above.

discriminator, rain began at 0024 EST, sea level pressure 993.5-hPa, hourly precipitation a trace, 6-hour precipitation total 0.04 inches, temperature 6.1° C, dew point temperature 3.3° C, 6-hour maximum temperature 10.6° C, 6-hour minimum temperature 6.1° C, 3-hour pressure tendency decreased 1.0-hPa.

The general flight categories and raw observations surrounding the period were as follows.

LIFR METAR KTYS 062053Z 30011KT 1SM BR BKN001 OVC120 12/11 A2932 RMK AO2 SFC VIS 3 RAE06 SLP922 P0000 60015 T01220111 56036=

LIFR SPECI KTYS 062059Z 30012KT 1 1/2SM BR OVC002 12/11 A2932 RMK AO2 SFC VIS 3 T01220111=

LIFR SPECI KTYS 062122Z 29010KT 3/4SM BR OVC002 12/11 A2932 RMK AO2 SFC VIS 3 T01170106=

LIFR METAR KTYS 062153Z 27008KT 1 1/2SM BR OVC002 12/11 A2936 RMK AO2 SFC VIS 6 PRESRR SLP936 T01170106=

LIFR METAR KTYS 062253Z 26007KT 1 1/2SM OVC003 11/09 A2936 RMK AO2 SFC VIS 10 CIG 002V008 SLP937 T01060089=

IFR SPECI KTYS 062313Z 23005KT 1 1/2SM SCT003 BKN006 OVC013 11/09 A2935 RMK AO2 SFC VIS 10 T01060089=

IFR SPECI KTYS 062331Z 25008KT 10SM SCT003 BKN006 OVC013 11/09 A2938 RMK AO2 PRESRR T01060089=

IFR METAR KTYS 062353Z 25009KT 10SM FEW003 SCT006 OVC009 11/08 A2938 RMK AO2 RAB32E42 SLP945 P0000 60015 T01060083 10139 20106 51022=

IFR METAR KTYS 070053Z 26010KT 10SM FEW003 SCT006 OVC009 10/07 A2940 RMK AO2 SLP950 T01000072=

MVFR SPECI KTYS 070123Z 26010KT 10SM OVC019 09/07 A2938 RMK AO2 T00890067=

MVFR METAR KTYS 070153Z 26006KT 10SM OVC022 09/07 A2936 RMK AO2 SLP937 T00890067=

MVFR METAR KTYS 070253Z 29009KT 10SM OVC026 08/06 A2936 RMK AO2 RAB29E41 SLP939 P0000 60000 T00830056 58007=

MVFR METAR KTYS 070353Z 28010KT 10SM -RA SCT012 OVC029 07/04 A2937 RMK AO2 RAB06 SLP942 P0003 T00720044=

MVFR METAR KTYS 070453Z 23006KT 10SM SCT012 OVC028 07/04 A2934 RMK AO2 RAE53 SLP934 P0001 T00670044 401780067=

MVFR METAR KTYS 070553Z 28009KT 10SM -RA SCT012 OVC028 06/03 A2935 RMK AO2 RAB24 SLP935 P0000 60004 T00610033 10106 20061 55010=

Turbulence encounter 0605Z

MVFR METAR KTYS 070653Z 27008KT 10SM BKN015 BKN025 OVC046 06/03 A2934 RMK AO2 RAE47 SLP932 P0001 T00560033=

MVFR SPECI KTYS 070737Z 27016G23KT 10SM -RA BKN013 OVC023 04/02 A2938 RMK AO2 PK WND 25026/0723 RAB06 P0001 T00440022=

A review of the observations for KTYS indicated that IFR conditions prevailed prior to the flight's departure with MVFR conditions in light rain with overcast clouds at the time of the turbulence encounter and the flight's arrival at the station. The 24-hour rainfall reported at 0800 EST for the station was 1.01 inches.

3.0 Sounding

To determine the vertical structure and state of the atmosphere over the accident site a High-Resolution Rapid Refresh (HRRR)⁹ numerical model data was retrieved from the NOAA Air

⁹ The HRRR is a National Oceanic and Atmospheric Administration (NOAA) real-time three-kilometer resolution, hourly-updated, cloud-resolving, convection-allowing atmospheric model, initialized by three-kilometer grids with

Resources Laboratory and plotted on a standard Skew T log P diagram¹⁰ using the complete Rawinsonde Observation RAOB program software¹¹. Figure 9 is a RAOB plot of the HRRR 0100 EST sounding over the turbulence encounter location from the surface through 250-hPa (approximately 34,000 ft).

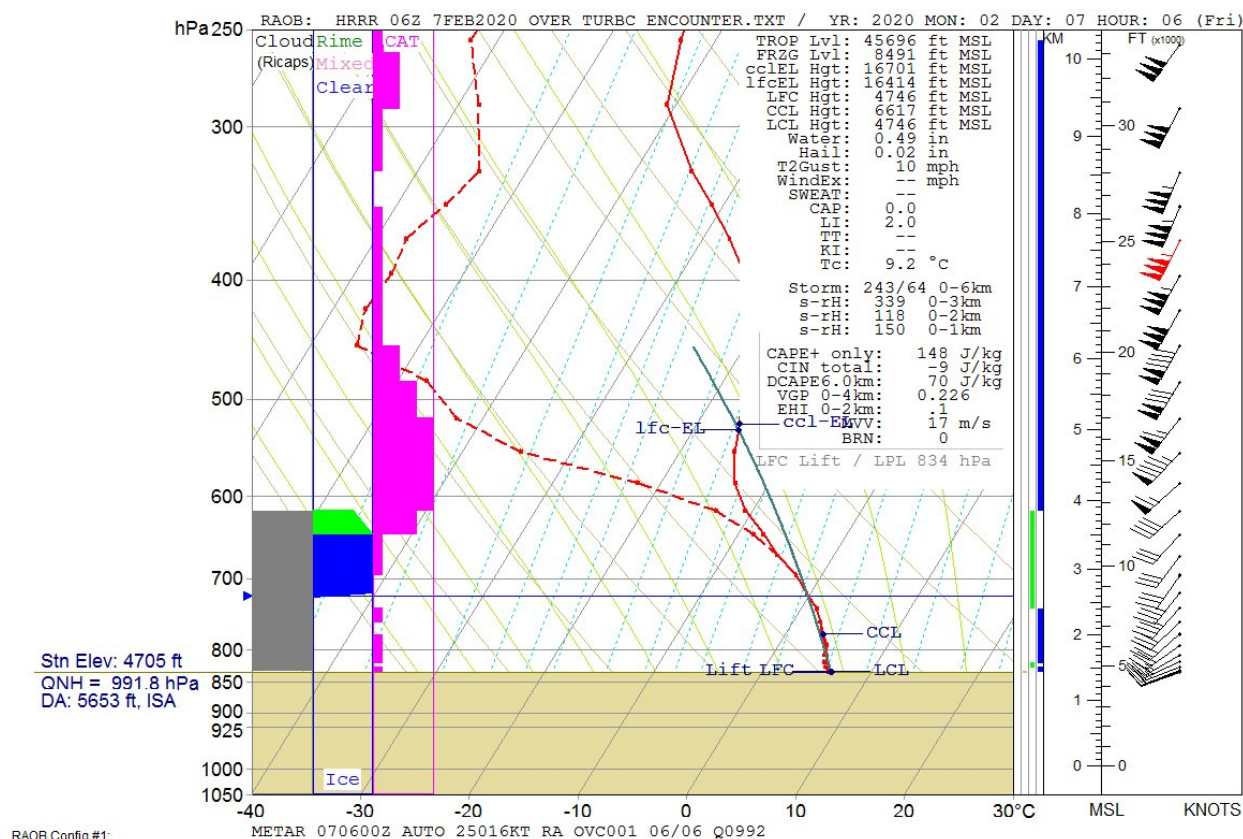


Figure 9 - HRRR sounding for 0100 EST over the turbulence encounter location

The RAOB sounding estimated the elevation at 4,705 ft, with a near surface temperature of 6.4° C (43.5° F), a dew point temperature of 6.3° C (43° F), with a relative humidity of 99%. The lifted condensation level (LCL)¹² and level of free convection (LFC)¹³ were identified at 41 ft agl (4,746 ft msl), with the convective condensation level (CCL)¹⁴ at 1,912 ft agl (6,617 ft msl). The sounding indicated a relative humidity greater than 98% from the LCL through approximately 12,500 ft, which supported a deep low-level layer of clouds capable of producing rain. The precipitable

three-kilometer radar assimilation. Radar data is assimilated in the HRRR every 15 minutes over a one-hour period.

¹⁰ Skew T log P diagram – is a standard meteorological plot or thermodynamic diagram using temperature and the logarithmic of pressure as coordinates, used to display winds, temperature, dew point, and various indices used to define the vertical structure of the atmosphere.

¹¹ RAOB software – The complete RAWinsonde OBservation program is an interactive sounding analysis program developed by Environmental Research Services, Matamoras, Pennsylvania, for plotting and analyzing upper air data

¹² Lifted Condensation Level (LCL) - the level at which a lifted parcel becomes saturated. The LCL height corresponds to cloud base height for forced ascent.

¹³ Level of Free Convection (LFC) - the last level where a parcel becomes buoyant, or "warmer" than the environmental temperature at the same level. The LFC represents the bottom of the layer containing CAPE.

¹⁴ 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.

water¹⁵ content was 0.49 inches. The RAOB depiction of the cloud layer is presented in gray on the left side of the diagram. The freezing level was identified at 8,491 ft (depicted by the blue horizontal line across the sounding) and the profile supported a layer of clear to rime icing above the freezing level to the cloud tops near 12,500 ft. Icing is also depicted on the left side of the sounding diagram with clear type ice in blue and rime type ice in green. The tropopause was identified at approximately 45,700 ft. Except for a layer between the surface and 12,500 ft, which was conditionally unstable, the atmosphere was characterized as stable with a Lifted Index¹⁶ of 2.0, and a Convective Available Potential Energy (CAPE)¹⁷ of 148 Joules/kilogram.

The HRRR 0100 EST sounding wind profile indicated a near surface wind from 250° at 16 knots with winds backing to the south-southwest with height, and with wind speeds increasing to over 50 knots by 14,000 ft. The mean 0 to 6 kilometer wind was from 213° at 85 knots, with the level of maximum wind identified at 25,000 ft being from 205° at 157 knots. At 20,000 ft (the level of the turbulence encounter) the wind was identified from 208° at 137 knots with a temperature of -18° C. The vertical wind shear at that level was 5.5 knots per 1,000 ft and the RAOB algorithm indicated a 92% probability of light turbulence at that level.

Figure 10 is a table of the observed sounding parameters of height, pressure (Pres), temperature (T), dew point (Td), relative humidity (RH), wind direction and speed (DD/FF), and RAOB derived clear air turbulence (CAT), low-level wind shear (LLWS), and icing potential from the surface through 33,000 ft.

¹⁵ Precipitable Water (PW) is a measure of the depth of liquid water at the surface that would result after precipitating all of the water vapor in a vertical column over a given location, usually extending from the surface to 300 mb.

¹⁶ Lifted Index (LI) - the difference between the lifted parcel temperature at 500 hPa and the 500 hPa temperature in the sounding. Negative values denote parcels that are warmer than the background 500 hPa temperatures and are thus buoyant or "unstable".

¹⁷ Convective Available Potential Energy (CAPE) – is the maximum buoyancy of an undiluted air parcel, related to the potential updraft strength of thunderstorms. On a thermodynamic diagram this is called positive area and can be seen as the region between the lifted parcel process curve and the environmental sounding, from the parcel's level of free convection to its level of neutral buoyancy.

Height (ft-MSL)	Pres (hPa)	T (C)	Td (C)	RH (%)	DD / FF (deg / kts)	CAT (FAA)	LLWS	Icing - Type (AFGWC method)
4705	834	6.4	6.3	99	249 / 16			
4737	833	6.3	6.0	98	249 / 15	LGT	MODRT	
4769	832	6.1	6.1	100	248 / 20	LGT	LIGHT	
4964	826	5.8	5.5	98	246 / 23			
5193	819	5.4	5.1	98	244 / 24	LGT		
5556	808	5.0	4.7	98	238 / 26	LGT		
6058	793	4.4	4.2	99	232 / 28	LGT		
6603	777	3.5	3.3	99	227 / 30			
7227	759	2.5	2.5	100	224 / 32	LGT		
7900	740	1.4	1.4	100	220 / 34			
8660	719	-0.4	-0.4	100	217 / 33			MDT Clear
9549	695	-2.4	-2.4	100	213 / 31	LGT		MDT Clear
10500	670	-5.2	-5.2	100	214 / 28	LGT		MDT Clear
11516	644	-7.7	-8.6	93	220 / 30	SVR		MDT Clear
12645	616	-10.7	-13.4	80	225 / 42	XTR		LGT Rime
13942	585	-13.2	-22.1	47	226 / 66	XTR		
15388	552	-15.0	-34.6	17	222 / 93	XTR		
16961	518	-16.3	-42.5	8	216 / 115	SVR		
18685	483	-17.2	-47.3	5	210 / 128	MDT		
20312	452	-18.7	-55.7	2	208 / 139	LGT		
21983	422	-21.1	-57.0	2	208 / 148	LGT		
23575	395	-24.2	-56.6	3	207 / 155	LGT		
25026	372				205 / 157			
25129	370	-27.5	-57.2	4		LGT		
26529	349				202 / 156			
26633	347	-31.1	-55.5	7				
28074	326	-34.8	-54.3	12	202 / 153	LGT		
30738	290				206 / 151			
30877	288	-40.8	-58.1	14		MDT		
33379	257				214 / 151			
33580	255	-43.2	-62.5	10		LGT		
35928	229				217 / 142			

Figure 10 - HRRR sounding parameters at 0100 EST and RAOB derived turbulence and icing potential

The RAOB algorithm indicated that a strong vertical wind shear layer existed between 6,800 ft through 14,000 ft and supported a high probability of moderate and greater turbulence. In the table above severe to extreme turbulence was indicated in several layers below the turbulence encounter between 11,500 ft and 17,000 ft.

An additional search of aircraft in situ reports over the area was conducted reviewing the Aircraft Meteorological Data Relay (AMDAR) data base. No in-situ reports were noted within 3 hours surrounding the period along the general route of flight.

4.0 Satellite Imagery

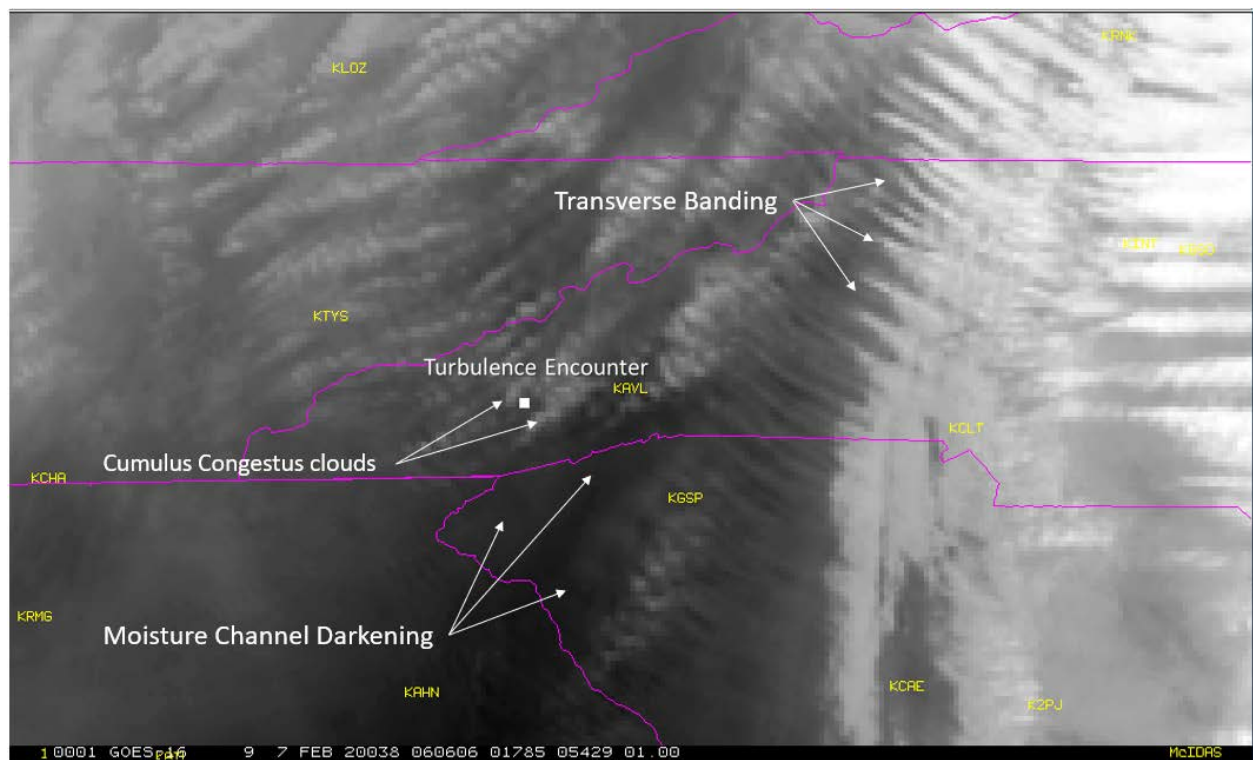
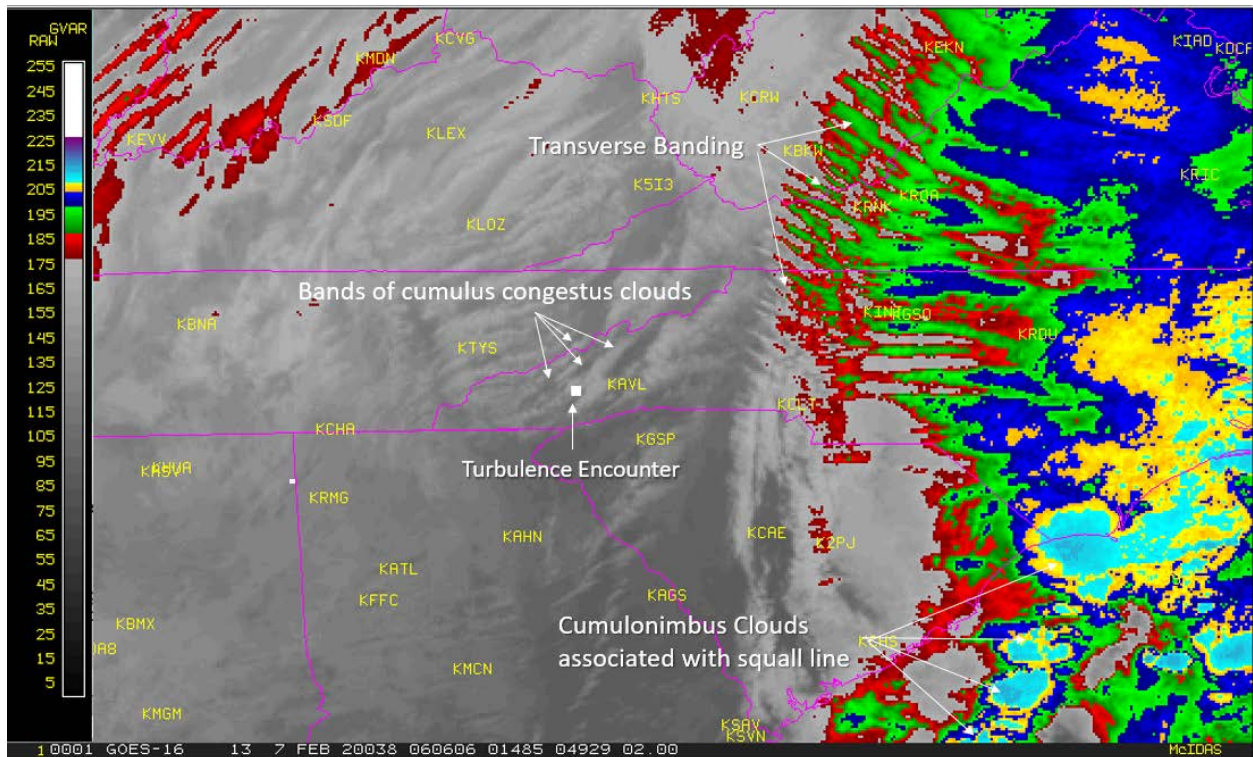
The Geostationary Operational Environmental Satellite number 16 (GOES-16) imagery data were obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System (McIDAS) software. The infrared long wave and mid-level tropospheric water vapor imagery were obtained for times surrounding the time of the accident, with the images

closest to the time of the accident documented below. The infrared long wave imagery (band 13) at a wavelength of 10.3 microns (μm) provided radiative cloud top temperatures with a nominal spatial resolution of 2 km. The mid-level tropospheric water vapor (band 9) at a wavelength of 6.9 μm provided images at a resolution of 2 km.

Figure 11 is the GOES-16 infrared image for 0106 EST at 2X magnification with a standard MB temperature enhancement curve applied to highlight the higher and often colder cloud tops associated with deep convection and high cirriform type clouds. The image depicted an area of cumulonimbus clouds (light blue) over eastern North Carolina and South Carolina near the coast well to the east of KCLT. The western band of high clouds north of KCLT displayed a transverse banding¹⁸ structure or wave structure, which is often observed with high-altitude turbulence. In the vicinity of the turbulence encounter several low-to-mid level cumulus congestus clouds in several bands were noted. These bands between KAVL and KTYS were associated with the bands of heavy rain reported at the stations during the period. The radiative cloud top temperature over the turbulence location ranged from 271 to 254 Kelvin or from -2° to -19° C respectively, which corresponded to cloud tops from 10,000 ft to 21,000 ft.

Figure 12 is the GOES-16 mid-level water vapor image for 0106 EST at 4X magnification. The image depicted an area of moisture channel darkening which indicated subsiding air immediately southeast of the turbulence location. Several bands of cumulus congestus type clouds were observed in the vicinity of the turbulence location, which were moving with the mean winds to the north-northeast with time.

¹⁸ Transverse Bands - Bands of clouds oriented perpendicular to the flow in which they are embedded. They often are seen best on satellite photographs. When observed at high levels (i.e., in cirrus formations), they may indicate severe or extreme turbulence. Transverse bands observed at low levels (called transverse rolls or T rolls) often indicate the presence of a temperature inversion (or cap) as well as directional shear in the low- to mid-level winds. These conditions often favor the development of strong to severe thunderstorms.



5.0 Weather Surveillance Radar Imagery

The closest NWS Weather Surveillance Radar 1988 Doppler (WSR-88D) was located 48 miles southeast of the turbulence encounter site in Greer (KGSP), South Carolina. The level II archive data were obtained from the NCEI using the Hierarchical Data Storage System and displayed using the NWS NEXRAD Interactive Viewer and Data Exporter and the GR2 Analysis¹⁹ software.

The WSR-88D is a S-band 10-centimeter wavelength radar with a power output of 750,000 watts, with a 28-foot parabolic antenna concentrating the energy into a 0.95° beam width. The radar produces three basic types of products reflectivity, radial velocity, and spectral width.

5.1 Volume Scanning Strategies

During the period the KGSP WSR-88D was operating in the precipitation mode volume scan pattern 212 (VCP-212), where the radar makes 14 different elevation scans in 4 ½ minutes. Figure 13 is a chart provides the beam height for the various elevation scans used in this scanning strategy.

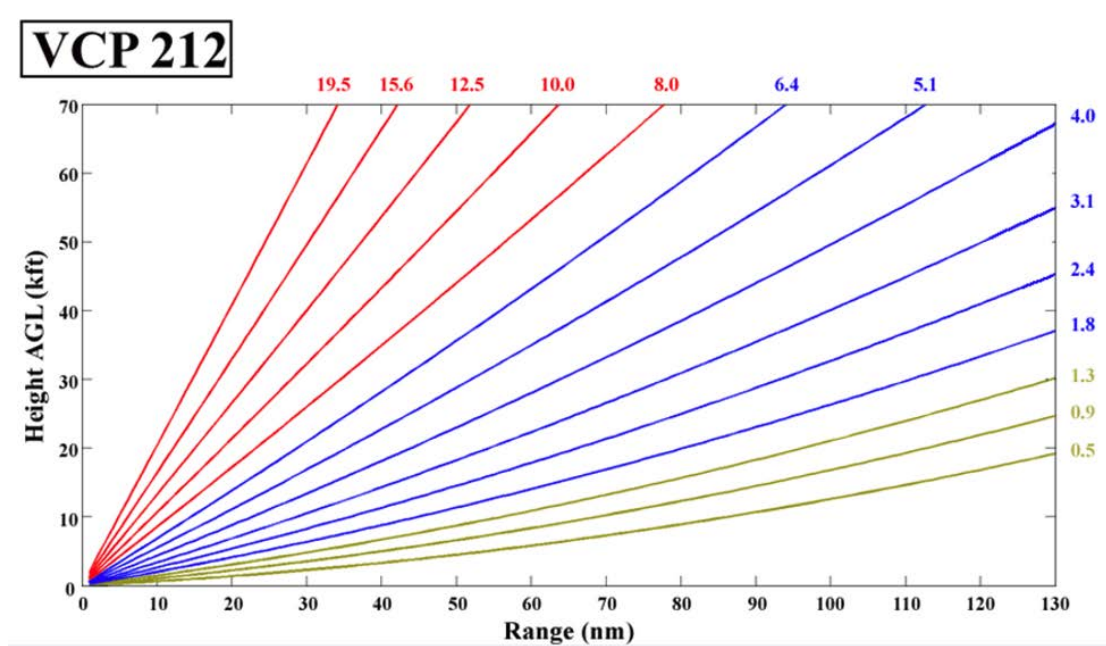


Figure 13 - VCP 212 scanning strategy

5.2 Beam Height Calculations

Assuming a standard refraction²⁰ of the WSR-88D radar beam with the KGSP antenna elevation at 1,068 ft, at a distance of 48 miles and considering a beam width of 0.95°, the following table shows the approximate heights for the radar beam center, base, and top over the turbulence location. The heights have been rounded to the nearest 10 ft. Only the standard beam heights were considered, not all 14 scans.

¹⁹ GR2Analysis program is available from Gibson Ridge Software, LLC, Suwanee, Georgia.

²⁰ Standard Refraction in the atmosphere is when the temperature and humidity distributions are approximately average, and values set at the standard atmosphere.

Elevation	Center	Base	Top	Width
0.48°	5,140 ft	2,720 ft	7,560 ft	4,840 ft
0.88°	6,670 ft	4,840 ft	9,080 ft	4,840 ft
1.32°	9,210 ft	6,790 ft	11,630 ft	4,840 ft
1.80°	11,750 ft	9,340 ft	14,170 ft	4,840 ft
2.42°	14,800 ft	12,390 ft	17,220 ft	4,840 ft
3.12°	18,460 ft	16,050 ft	20,880 ft	4,840 ft

Based on the radar calculations the KGSP WSR-88D 3.12° elevation beam best covered the altitude over the turbulence encounter and represented the conditions along the flight path. The WSR-88D lowest elevation 0.5° radar scan is typically used in radar displays available in flight dispatch and preflight briefing stations or on the internet, such as the NWS AWC website. Both displays will be documented below.

5.3 Reflectivity

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors, it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in decibels (dBZ²¹) and is a general measure of echo intensity. Figure 14 relates the NWS former video integrator and processor (VIP) intensity levels (1-6) versus the WSR-88D's display levels (0-15), precipitation mode reflectivity in decibels (DBZ), and rainfall rates.

NWS VIP/DBZ CONVERSION TABLE			
NWS VIP	WSR-88D LEVEL	PREC MODE DBZ	RAINFALL
0	0	< 5	
	1	5 to 9	
	2	10 to 14	
1 Very Light	3	15 to 19	.01 in/hr
	4	20 to 24	.02 in/hr
	5	25 to 29	.04 in/hr
2 Light to Moderate	6	30 to 34	.09 in/hr
	7	35 to 39	.21 in/hr
3 Strong	8	40 to 44	.48 in/hr
4 Very Strong	9	45 to 49	1.10 in/hr
5 Intense	10	50 to 54	2.49 in/hr
6 Extreme	11	55 to 59	>5.67 in/hr
	12	60 to 64	
	13	65 to 69	
	14	70 to 74	
	15	> 75	

Figure 14 - NWS VIP, WSR-88D intensity levels, reflectivity ranges, and rainfall rates

²¹ dBZ - $10 \log Z_e$

The FAA has taken the NWS previous 1 to 6 VIP intensity levels and has redefined them for pilots in Advisory Circular AC 00-24C - “Thunderstorm”. That AC further defines echoes less than 30 dBZ as “light” in intensity, “moderate” echoes 30-40 dBZ, “heavy” with echoes of >40-50 dBZ, and “extreme” intensity with echoes above >50 dBZ. These are the standard radio phraseology terms used by air traffic controllers to describe weather conditions to pilots as shown in figure 15. Center controllers only depict echoes over 30 dBZ on their Weather And Radar Processor (WARP) displays.

Reflectivity (dBZ) Ranges	Weather Radar Echo Intensity Terminology
< 30 dBZ	Light
30 – 40 dBZ	Moderate
>40 – 50 dBZ	Heavy
>50 dBZ	Extreme

Figure 15 - Radar reflectivity intensity levels and terminology

5.4 Base Reflectivity Imagery

Figure 16 is the KGSP WSR-88D 0.5° base reflectivity image at 0059 EST with the accident aircrafts flight path overlaid in white. The image depicts the flight overflying several bands of echoes approaching KTYS, where the turbulence was encountered.



Figure 16 - KGSP WSR-88D 0.5° base reflectivity image for 0059 EST with the flight track

Figure 17 is a collection of the KGSP WSR-88D base reflectivity radar images for the various elevation scans from 0.48° through 3.12° at approximately 0105 EST with the flight track overlaid. The turbulence location was located over the eastern side of one of the band of echoes, with the strongest portion of the echo identified on the 0.88° scan with reflectivities of 47.5 dBZ “heavy intensity” near 6,600 ft. At the aircraft’s altitude echoes of 27.5 dBZ were identified within 2 miles of the flight path to approximately 18,388 ft.

The echo tops product indicated the maximum height of the 18.5 dBZ extended to 18,500 ft in the vicinity of the turbulence event, with actual cloud tops several thousand feet higher than this level.

A review of the FAA Consolidated Storm Prediction for Aviation (CoSPA) imagery surrounding the period indicated no lightning activity or echo tops in excess of 20,000 ft in the immediate vicinity of the turbulence location in the hours preceding and following the turbulence event. None of the echoes in the vicinity of the turbulence location were noted producing any cloud-to-ground lightning.

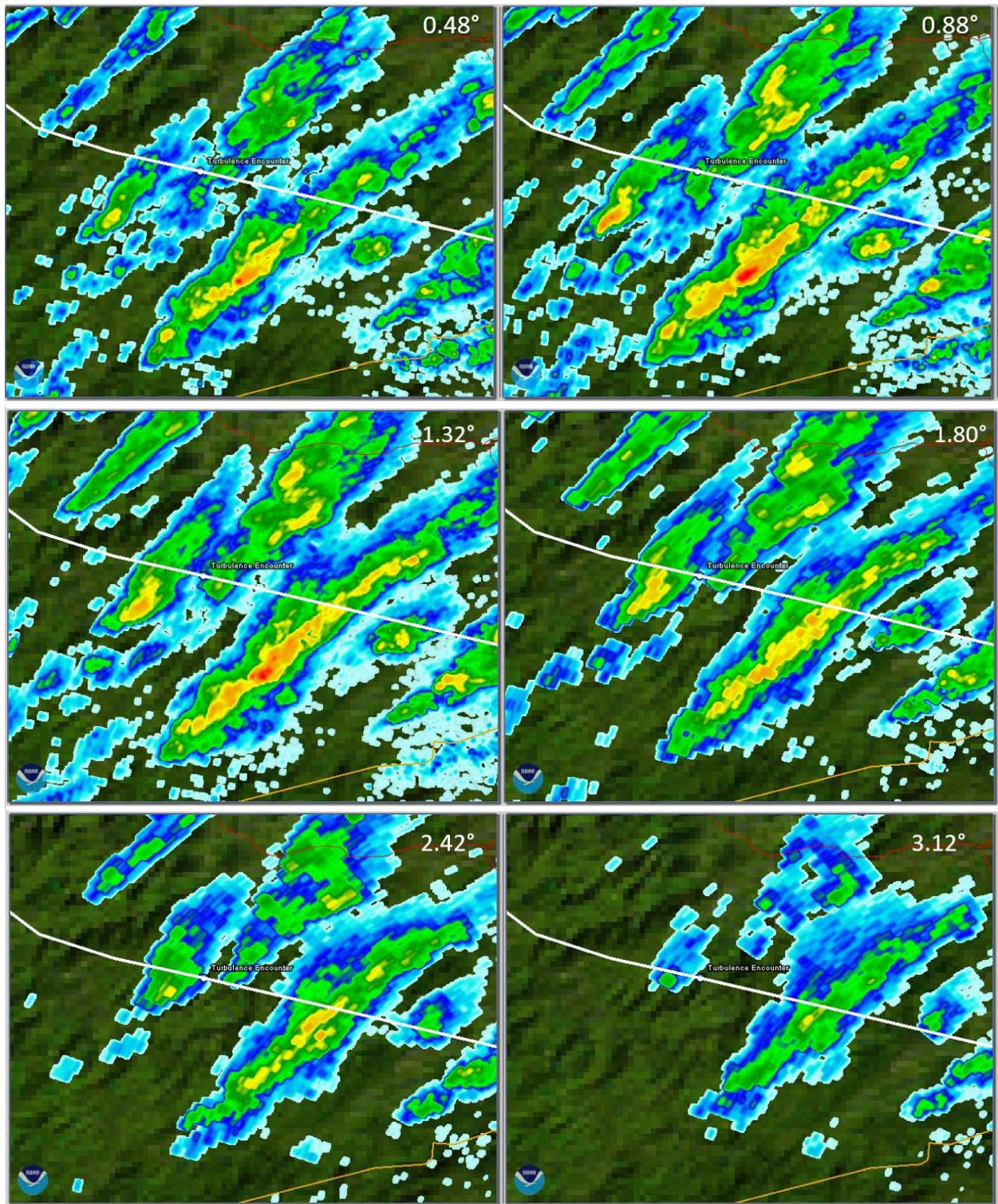
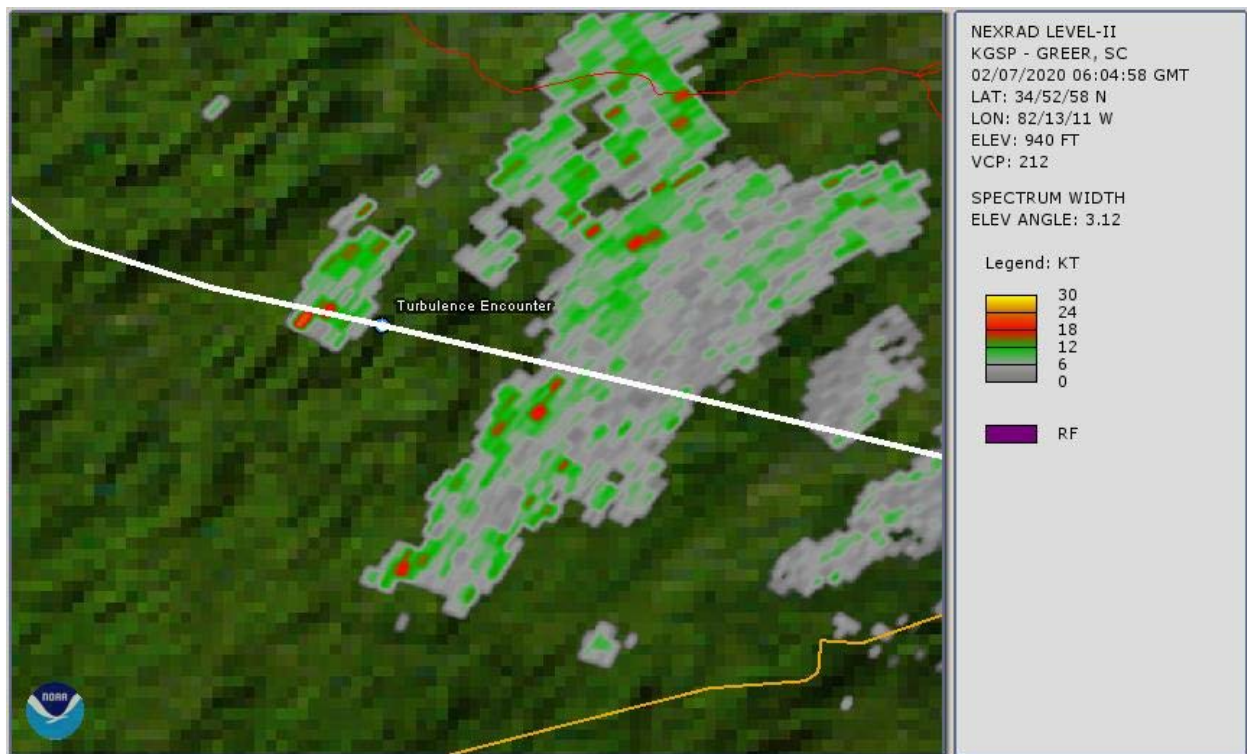


Figure 17 - KGSP WSR-88 base reflectivity images for elevation scans from 0.5° through 3.12° for 0105 EST

5.5 Spectrum Width Image

The WSR-88D spectrum width product was also reviewed. Spectrum width depicts a measure of the variability of the radial velocity estimates due to the presence of wind shear, turbulence, and/or the quality of velocity samples. It is used to estimate turbulence associated with boundaries, thunderstorms, mesocyclones and other vortices in convective lines. Low spectrum width values (gray shades) indicate smooth or uniform flow, while high values (red to yellow) denote turbulent or variable flow. Figure 18 is the KGSP WSR-88D 3.12° spectrum width product for 0105 EST, which depicted significant shear in the echoes over the flight path and in the immediate vicinity of the turbulence encounter near 22.5 knots.



0.88Figure 18 - KGSP WSR-88D 3.32° spectrum width product for 0105 EST with the flight track

6.0 Pilot Reports

A search of the NWS data base provided the following pilot reports (PIREPs) within approximately 100 miles along the route of flight between 1900 through 0300 EST, with the reports below 28,000 ft included below. The reports are provided in standard code and abbreviations and followed by a decoded report in plain language with time converted to local EST. The report recorded by air traffic control relating to the accident is included in bold italic print. The reports surrounding the period were as follows:

TYS UA /OV VXV080005/TM 0007/FL280/TP A319/TB MOD/RM ZTLFD

TYS routine pilot report (UA); Over – Volunteer VORTAC²²; Time – 1907 EST; Flight Level²³ – 280; Type aircraft – Airbus A-319; Turbulence – moderate; Remarks – entered from Atlanta Center Flight Data.

TRI UA /OV GCY/TM 0040/FL100/TP SR22/TB MOD/IC MOD CLR

Tri-city Airport (TRI), Bristol/Johnson/Kingsport, Tennessee, routine pilot report (UA); Over – Greeneville-Green County Municipal Airport (GCY), Greeneville, Tennessee, routine pilot report (UA); Time – 1940 EST; Altitude 10,000 ft; Type aircraft – Cirrus SR22; Turbulence – moderate; icing – moderate clear type ice.

TYS UA /OV 20 E TYS/TM 0040/FL120/TP A319/TB MOD

TYS routine pilot report (UA) – Over – 20 miles east of TYS; Time – 1940 EST; Altitude – 12,000 ft; Type aircraft – Airbus A-319; Turbulence – moderate.

RHP UA /OV HRS/TM 0108/FL160/TP LJ60/TB MOD BLO ABV 160-120/RM DOWN DRAFT ZTLFD

Western Carolina Regional Airport (RHP), Andrews, North Carolina routine pilot report (UA); Over – Harris VORTAC, Harris, Georgia (HRS); Time – 2008 EST; Altitude – 16,000 ft; Type aircraft – Bombardier Aerospace Learjet 60; Turbulence – moderate below and above 16,000 through 12,000 ft; Remarks – downdrafts.

TYS UUA /OV 30 SE TYS/TM 0109/FL130/TP CRJ9/TB MOD-SEV DURD 130-100

TYS urgent pilot report (UUA); Over – 30 miles southeast of TYS, Time – 2009 EST; Altitude – 13,000 ft; Type aircraft – Bombardier Regional Jet CRJ-900; Turbulence – moderate to severe turbulence during descent between 13,000 and 10,000 ft.

AVL UA /OV SUG/TM 0212/FL280/TP E75/TB MOD CONS CHOP/RM ZTLFD

AVL routine pilot report (UA); Over – Sugarloaf Mountain VORTAC; Time – 2112 EST; Flight Level – 280; Type aircraft – Embraer ERJ-175; Turbulence – continuous moderate chop; Remarks – entered from Atlanta Center Flight Data.

RHP UUA /OV HRS/TM 0237/FL160/TP B712/TB MOD-SEV/RM NO DAMAGE NO INJURIES ZTLFD

Western Carolina Regional Airport (RHP), Andrews, North Carolina, urgent pilot report (UUA); Over – Harris VORTAC, Time – 2137 EST; Altitude – 16,000 ft; Type aircraft – Boeing B-717; Turbulence – moderate-to-severe; Remarks – no damage or injuries reported entered by Atlanta Center Flight Data.

TYS UUA /OV VXV140030/TM 0248/FL120/TP E145/TB SEV 120-150

TYS urgent pilot report (UUA); Over – 30 miles southeast or on the 140° azimuth of VXV VORTAC; Time – 2148 EST; Altitude – 12,000 ft; Type aircraft – Embraer ERJ-145; Turbulence – severe turbulence between 12,000 and 15,000 ft.

AVL UA /OV 8 E AVL/TM 0252/FL090/TP CRJ9/TB MOD/RM TAPERED OFF AROUND 078

AVL routine pilot report (UA); Over – 8 miles east of AVL; Time – 2152 EST; Altitude – 9,000 ft; Type aircraft – Bombardier CRJ-900; Turbulence – moderate; Remarks – turbulence tapered off around 7,800 ft.

RHP UA /OV HRS/TM 0255/FL130/TP MD88/TB SEV/RM NO INJURIES OR DAMAGES REPORTED ZTLFD

²² A VORTAC is a radio-based navigational aid for aircraft pilots consisting of a co-located VHF omnidirectional range (VOR) beacon for azimuth data and a tactical air navigation system (TACAN) beacon for distance. Unless otherwise noted the VORTAC is co-located with the airport city identified.

²³ Flight level (FL280) – is a reference to the aircraft's altitude referenced to 29.92 inches of Hg or constant pressure surface. In the United States aircraft above 18,000 ft fly constant pressure altitudes in hundreds of feet.

PHP routine pilot report (UA); Over – HRS VORTAC; Time – 2155 EST; Altitude – 13,000 ft; Type aircraft – McDonnell Douglas MD-88; Turbulence – severe; Remarks – no injuries or damage reported entered by Atlanta Center Flight Data.

RHP UUA /OV HRS090020/TM 0304/FL160/TP MD90/TB SEV/RM CAN/T CONTROL ALTITUDE ZTLFD

PHP urgent pilot report (UA); Over – 20 miles east or on 090° azimuth from HRS VORTAC; Time – 2204 EST; Altitude – 16,000 ft; Type aircraft – McDonnell Douglas MD-90; Turbulence – severe; Remarks – unable to control or maintain altitude entered by Atlanta Center Flight Data.

TYS UA /OV VXV110015/TM 0310/FL120/TP E145/TA M08/TB MOD 100-120/IC LGT RIME/RM LGT TURB DURC

TYS routine pilot report (UA); Over – 15 miles east-southeast or on 110° azimuth of VXV VORTAC; Time – 2210 EST; Altitude – 12,000 ft; Type aircraft - Embraer ERJ-145; Turbulence – moderate turbulence between 10,000 and 12,000 ft; Icing – light rime type ice; Remarks – light turbulence during climb.

TYS UA /OV VXV090040/TM 0341/FL170/TP CRJ7/TB CONS MOD BLO 170/RM ZTLFD

TYS routine pilot report (UA); Over – 40 miles east on 090° azimuth of VXV VORTAC; Time – 2241 EST; Altitude – 17,000 ft; Type aircraft - Bombardier CRJ-700; Turbulence – continuous moderate turbulence below 17,000 ft; Remarks – entered from Atlanta Center Flight Data.

AVL UA /OV SUG360005/TM 0422/FL240/TP E215/TB MOD 240-160/RM ZTLFD

AVL routine pilot report (UA); Over – 5 miles north of SUG VORTAC; Time – 2322 EST; Flight level – 240; Type aircraft – type unknown; Turbulence – moderate between 24,000 and 16,000 ft; Remarks – entered by Atlanta Center Flight Data.

TYS UA /OV VXV230003/TM 0430/FL029/TP CRJ9/SK SCT012 OVC029/WX FV10SM -RA/TA 07/WV 28006/TB NA/IC NA/RM BASES 029 SMOOTH RIDE ON FINAL

TYS routine pilot report (UA); Over – 3 miles southeast or on 230° azimuth of VXV VORTAC; Altitude 2,900 ft; Type aircraft - Bombardier CRJ-900; Sky cover – scattered clouds with bases at 1,200 ft and overcast at 2,900 ft; Weather – flight visibility 10 statute miles in light rain; Temperature – 7° C; Wind – from 280° at 6 knots; Turbulence – none; Icing – none; Remarks – cloud bases at 2,900 ft with smooth ride on final.

AVL UA /OV SUG290010/TM 0434/FL080/TP CRJ2/TB MOD/RM ZTLFD

AVL routine pilot report (UA); Over – 10 miles west or 290° azimuth of SUG VORTAC; Time – 2334 EST; Altitude – 8,000 ft; Type aircraft - Bombardier CRJ-200; Turbulence – moderate; Remarks – entered by Atlanta Center Flight Data.

CLT UA /OV CLT340060/TM 0520/FL170/TP C680/TB LGT-MOD 170-120/RM ZTLFD

CLT routine pilot report (UA); Over – 60 miles northeast or 340° azimuth of CLT VORTAC; Time – 0020 EST; Altitude – 17,000 ft; Type aircraft – Cessna Citation Sovereign; Turbulence – light to moderate turbulence between 17,000 and 12,000 ft; Remarks – entered by Atlanta Center Flight Data.

AVL UA /OV SUG360010/TM 0546/FL160/TP CRJ9/TB LGT-MOD CHOP/RM HARD TO HOLD ALTITUDE ZTLFD

AVL routine pilot report (UA); Over – 10 miles north of SUG VORTAC; Time -0046 EST; Altitude – 16,000 ft; Type aircraft - Bombardier CRJ-900; Turbulence – light-to-moderate chop; Remarks – hard to hold altitude; Remarks – entered by Atlanta Center Flight Data.

HKY UUA /OV BZM320015/TM 0558/FL170/TP CRJ9/TB OCNL SEV CAT 170-160/RM NO DAMAGES OR INJURIES RTEPORTED ZTLFD

HKY urgent pilot report (UUA); over – 15 miles northwest or 315° azimuth of Barretts Mountain VORTAC, Hickory, North Carolina; Time – 0058 EST; Altitude – 17,000 ft; Type aircraft - Bombardier CRJ-900; Turbulence – occasional severe clear air turbulence between 17,000 and 16,000 ft; Remarks – no damage or injuries reported, entered by Atlanta Center Flight Data.

TYS UA /OV VXV130005/TM 0600/FL190/TP CRJ9/TB MOD CAT 190-160/RM DURC ZTLFD

TYS routine pilot report (UA); over – 5 miles southeast or 130° azimuth of VXV VORTAC; Time – 0100 EST; Flight level – 190; Type aircraft - Bombardier CRJ-900; Turbulence – moderate clear air turbulence between 19,000 and 16,000 ft; Remarks – during climb entered by Atlanta Center Flight Data.

TYS UUA /OV VXV150055/TM 0600/FL190/TP CRJ7/TB SEV CAT 190-160/RM DURD FLIGHT ATTENDANT INJURED NECK AND ANKLE ZTLFD

TYS urgent pilot report (UUA); over – 55 miles southeast or 150° azimuth of VXV VORTAC; Time – 0100 EST; Flight level – 190; Type aircraft - Bombardier CRJ-700; Turbulence – severe clear air turbulence between 19,000 and 16,000 ft; Remarks – encountered during descent, flight attendant injured neck and ankle entered by Atlanta Center Flight Data.

TYS UUA /OV VXV120050/TM 0608/FL160/TP CRJ9/SK SCT012 OVC028/WX FV10SM -RA/TA 06/WV 27009/TB TB SEV 190-160/IC NA

TYS urgent pilot report (UUA); over – 50 miles southeast or 120° azimuth of VXV VORTAC; Time – 0108 EST; Altitude – 16,000 ft; Type aircraft – Bombardier CRJ-900; Sky cover – scattered clouds at 1,200 ft overcast at 2,800 ft; Weather – flight visibility 10 miles in light rain; Temperature – 6° C; Wind – 270° at 9 knots; Turbulence – severe turbulence between 19,000 and 16,000 ft; Icing – none.

TYS UA /OV TYS/TM 0751/FL020/TP E75L/SK BKN015 BKN025 OVC046/WX 10SM/TA 06/WV 27017/TB NA/IC NA/RM BASES 020 -5 KNOTS ON FINAL

TYS routine pilot report (UA); over – TYS; Time – 0251 EST; Altitude – 2,000 ft; Type aircraft – Embraer ERJ-175; Sky cover – broken clouds at 1,500 ft, broken at 2,500 ft, and overcast at 4,600 ft; Weather – flight visibility 10 miles; Temperature – 6° C; Wind – 270° at 17 knots; Turbulence – none; Icing – none; Remarks – cloud bases at 2,000 ft with a loss of 5 knots on final.

Of the 23 PIREPs recorded during the period from 1900 through 0300 EST, seven were urgent reports. Of the 23 PIREPs there were 21 reports of turbulence with intensities reported as light-to-moderate (2), moderate (11), moderate-to-severe (2), and severe (6). The most common altitudes reported for the turbulence layer were between 10,000 ft and 19,000 ft. The accident aircraft report entered by air traffic control also recorded the altitude as 19,000 ft. The reports were clustered near the North Carolina and Tennessee border and in the vicinity of the accident site. Some of the significant remarks noted with the turbulence reports included inability or difficulty maintaining altitude (2), and turbulence with down drafts. Several of the severe intensity encounters confirmed that no injuries or damage were noted; however, one report discussed an injured flight attendant, which may have originated from the accident airplane.

For reference figure 19 is from the Aeronautical Information Manual (AIM), Safety of Flight, section 7-1-23, PIREPs Relating to Turbulence, Turbulence Reporting Criteria Table.

Turbulence Reporting Criteria Table

Intensity	Aircraft Reaction	Reaction Inside Aircraft	Reporting Term –Definition
Light	Turbulence that momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw). Report as Light Turbulence ; ¹ or Turbulence that causes slight, rapid and somewhat rhythmic bumpiness without appreciable changes in altitude or attitude. Report as Light Chop .	Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly. Food service may be conducted and little or no difficulty is encountered in walking.	Occasional—Less than ¹ / ₃ of the time. Intermittent— ¹ / ₃ to ² / ₃ . Continuous—More than ² / ₃ .
Moderate	Turbulence that is similar to Light Turbulence but of greater intensity. Changes in altitude and/or attitude occur but the aircraft remains in positive control at all times. It usually causes variations in indicated airspeed. Report as Moderate Turbulence ; ¹ or Turbulence that is similar to Light Chop but of greater intensity. It causes rapid bumps or jolts without appreciable changes in aircraft altitude or attitude. Report as Moderate Chop . ¹	Occupants feel definite strains against seat belts or shoulder straps. Unsecured objects are dislodged. Food service and walking are difficult.	NOTE 1. Pilots should report location(s), time (UTC), intensity, whether in or near clouds, altitude, type of aircraft and, when applicable, duration of turbulence. 2. Duration may be based on time between two locations or over a single location. All locations should be readily identifiable. EXAMPLES: a. Over Omaha. 1232Z, Moderate Turbulence, in cloud, Flight Level 310, B707. b. From 50 miles south of Albuquerque to 30 miles north of Phoenix, 1210Z to 1250Z, occasional Moderate Chop, Flight Level 330, DC8.
Severe	Turbulence that causes large, abrupt changes in altitude and/or attitude. It usually causes large variations in indicated airspeed. Aircraft may be momentarily out of control. Report as Severe Turbulence . ¹	Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Food Service and walking are impossible.	
Extreme	Turbulence in which the aircraft is violently tossed about and is practically impossible to control. It may cause structural damage. Report as Extreme Turbulence . ¹		

¹ High level turbulence (normally above 15,000 feet ASL) not associated with cumuliform cloudiness, including thunderstorms, should be reported as CAT (clear air turbulence) preceded by the appropriate intensity, or light or moderate chop.

Figure 19 - AIM Turbulence Reporting Criteria

7.0 NWS Forecasts

The standard aviation weather forecasts issued surrounding the period were documented and are included below.

7.1 Terminal Aerodrome Forecasts

The NWS Knoxville/Tri Cities (KMRX), Weather Forecast Office (WFO) located in Morristown, Tennessee, was responsible for the issuance of the Terminal Aerodrome Forecast (TAF) for KTYL, while the NWS Greenville-Spartanburg, South Carolina WFO was responsible for the TAF for KAVL. A TAF is a concise statement of the expected meteorological conditions at an airport during a specified period (usually 24 hours). TAFs are valid for a 5 mile radius around an airport's center point. The forecasts issued at 2158 EST, which was used for the release of the flight (see attachment 2), was an amended forecast and was as follows.

AMD TAF KTY5 070258Z 0703/0724 31006KT 6SM BR OVC020
TEMPO 0703/0707 3SM -SHRA BR
 FM070700 27013KT 4SM BR OVC015
 TEMPO 0707/0711 2SM -SHRA BR OVC008
 FM071100 25018KT P6SM -SHRA OVC011
 TEMPO 0711/0714 4SM -SHRASN OVC008
 FM071400 25021KT P6SM OVC022
 PROB30 0714/0719 4SM -SHRASN OVC015
 FM072000 26020KT P6SM OVC035=

The forecast current for the estimated time of arrival expected from 2200 through 0200 EST, wind from 310° at 6 knots, visibility 6 miles in mist, with a ceiling overcast at 2,000 ft agl, with a temporary period of 3 miles in light rain showers and mist.

The next scheduled TAF was issued at 0037 EST and was valid from 0100 EST for a 24-hour period and was as follows.

TAF KTY5 070537Z 0706/0806 26011KT 4SM BR OVC015
TEMPO 0706/0710 2SM -SHRA BR OVC008
 FM071000 25018G25KT P6SM -SHRA OVC011
 TEMPO 0710/0714 4SM -SHRASN OVC008
 FM072000 25016KT P6SM OVC035
 FM072300 24007KT P6SM BKN040=

The forecast issued at 0037 EST after the flight was enroute expected wind from 260° at 11 knots, visibility 4 miles in mist, ceiling overcast at 1,500 ft agl, with a temporary period between 0100 and 0500 EST of visibility 2 miles in light rain showers and mist, ceiling overcast at 800 ft agl.

7.2 Winds and Temperature Aloft Forecast

The Winds and Temperature Aloft Forecast²⁴ (FD) current for the route of flight from 3,000 ft through 39,000 ft (data for 45,000 and 53,000 ft has been deleted) valid for 0100 EST and for use between 2300 and 0400 EST.

WINDS ALOFT FORECASTS
DATA BASED ON 070000Z
VALID 070600Z FOR USE 0200-0900Z. TEMPS NEG ABV 24000

FT	3000	6000	9000	12000	18000	24000	30000	34000	39000
GSP	2338	2347+05	2234+00	2373-06	7130-11	7035-23	704240	725345	725051
CAE	2241	2466+09	2383+03	7205-01	7115-10	7025-20	712936	725444	724754
FLO	2443	2453+10	2357+05	2275+00	2156-10	2059-19	219635	723146	735658
TRI		2222+04	2133-01	2139-07	7220-17	7147-25	705141	704547	714051
TYS	3111	2324+00	2136-04	2137-10	7102-21	7044-27	713839	712844	711647

²⁴ Derived from FBUS31 KWNO winds aloft bulletin.

The forecast for TYS for 18,000 ft was for a wind from 210° at 102 knots with a temperature of -21° C, and at 24,000 ft from 200° at 144 knots with a temperature of -27° C. The forecast wind forecast indicated a potential vertical wind shear between 18,000 and 24,000 ft of 42 knots or 7 knots per 1,000 ft.

According to FAA Advisory Circular AC 00-30C “Clear Air Turbulence Avoidance”, dated March 2016, moderate clear air turbulence (CAT) is considered likely when the vertical wind shear is 5 knots per 1,000 feet or greater, and/or the horizontal wind shear is 40 knots per 150 miles or greater.

7.3 Graphic Turbulence Guidance

The Graphic Turbulence Guidance (GTG) was developed by the National Center for Atmospheric Research (NCAR) and is now run operationally at NOAA NCEP and is available to users on the AWC website²⁵ from the surface to 45,000 ft. The current GTG version 3.0 model is generated from the NOAA Rapid Refresh (RAP) numerical model with a horizontal spacing of 13.5 kilometers with 50 vertical levels, and provides a computer-generated four-dimensional forecast related to the expected intensity of atmospheric turbulence provided in eddy dissipation rate (EDR). EDR ($\text{m}^{2/3} \text{s}^{-1}$) is aircraft independent and is the International Civil Aviation Organization (ICAO) standard for turbulence reporting. EDR varies from close to 0, “smooth”, to near 1, “extreme” for most aircraft types. NCAR defines the following EDR values to various aircraft weight classes and turbulence intensities and is included as figure 20, the Canadair CRJ900 fits the medium weight category²⁶.

AC weight class	Estimated EDR Threshold * 100			
	Light	Moderate	Severe	Extreme
Light	13	16	36	64
Medium (Large)	15	20	44	79
Heavy	17	24	54	96

Figure 20 - EDR values versus turbulence intensity for various aircraft weight classes

While the current GTG model does not consider Convectively Induced Turbulence (CIT) associated with cumulus type clouds, a new version of the GTGN for “Nowcast” model uses a higher HRRR grid resolution which resolves convection better, adds convective induced turbulence (CIT) parameterization, includes in situ observations of EDR from aircraft, utilizes the WSR-88D reflectivity, spectrum width, and NEXRAD/NCAR Turbulence Detection Algorithm (NTDA), and produces a 3-dimensional mosaic of EDR with an update rate of 5-minutes, with a 2 km horizontal 3,000 ft vertical resolution. This new GTGN version 4 is being run at AWC in a demonstration and evaluation phase and plans to transition to operations in late 2020 to operational use and specifically addresses convectively induced turbulence.

²⁵ <http://www.aviationweather.gov/turbulence/gtg>

²⁶ Medium (or large) category aircraft – is defined as an aircraft with a maximum takeoff weight between 15,500 to 300,000 pounds (examples include A320, B737, MD80, and Gulfstream business jets).

The NCAR was contacted and requested to re-run the current GTG and GTGN models for comparison (see Attachment 1). The output is referenced to EDR values, which are further defined for a medium category aircraft with the turbulence intensity in figure 21, which depicts values on a scale of 0 to 1.0. NCAR researchers have documented that moderate turbulence is typically encountered with EDR values between 0.20 and 0.43, severe between 0.44 and 0.79, and extreme with values over 0.80.

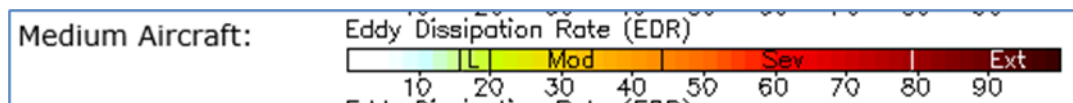


Figure 21 - EDR values for a medium category aircraft

Figure 22 is the GTG 2-hour forecast for 0100 EST (0600Z) for FL180, FL200, and FL220 with the turbulence location noted by a star. These were available on the NWS AWC website at the time of the accident. The image depicted EDR values of 0.2 to 0.4, with the EDR values increasing with decreasing altitude near FL180.

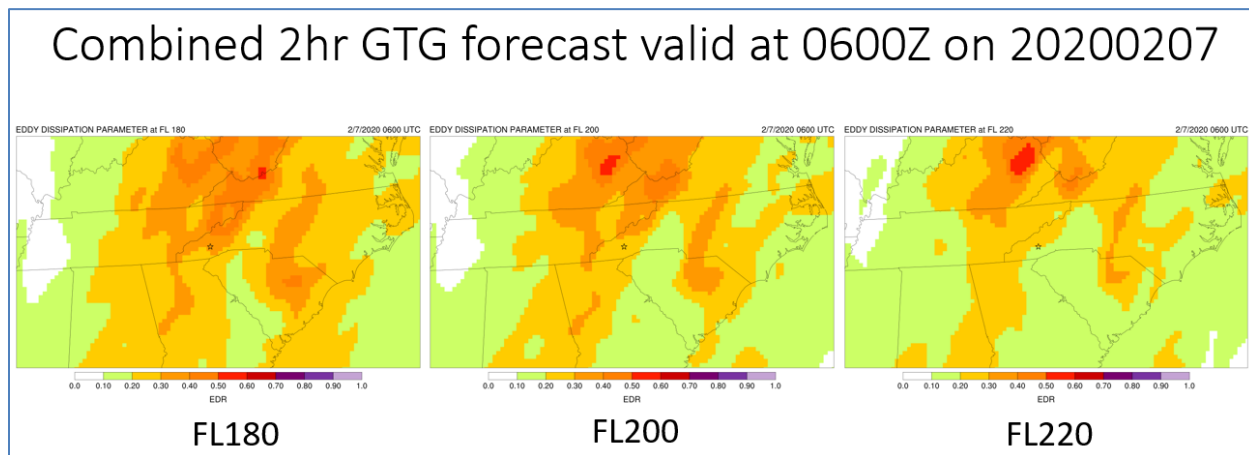


Figure 22 - NCAR GTG for 0100 EST (0600Z) for FL180, FL200, and FL220

Figures 23-25 are the NCAR GTGN products for 0045 EST (0545Z), 0100 EST (0600Z), and 0115 EST (0615Z), respectively. The GTGN at 0100 EST (0600Z) had higher EDR values between 0.3 to 0.6, with values of 0.6 to 0.8 within close proximity of the turbulence location.

GTGN valid at 0545Z on 20200207

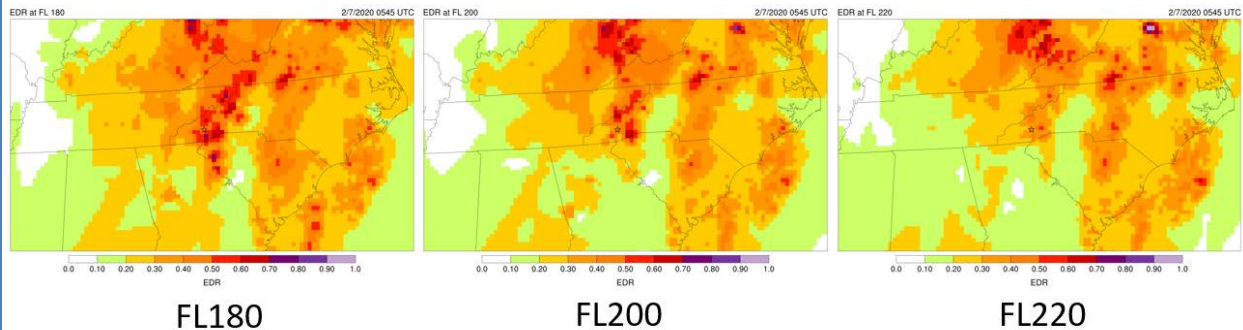


Figure 23 - NCAR GTGN valid for 0045 EST (0545Z) for FL180, FL200, and FL220

GTGN valid at 0600Z on 20200207

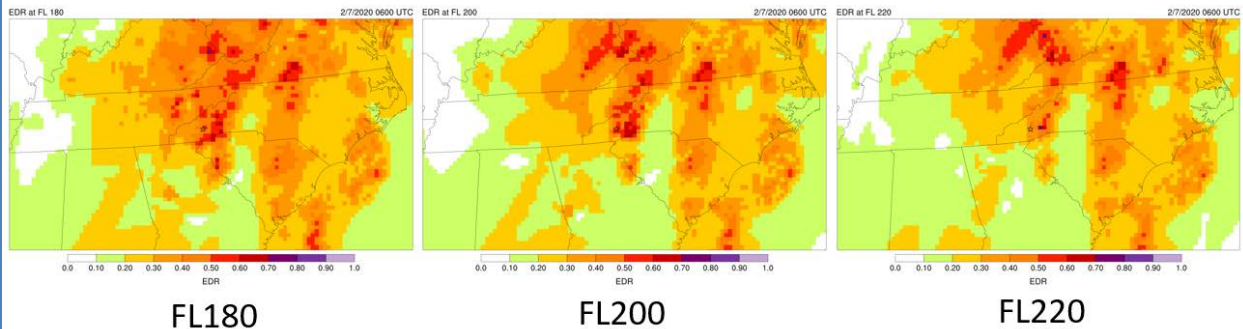


Figure 24 - NCAR GTGN valid for 0100 EST (0600Z) for FL180, FL200, and FL220

GTGN valid at 0615Z on 20200207

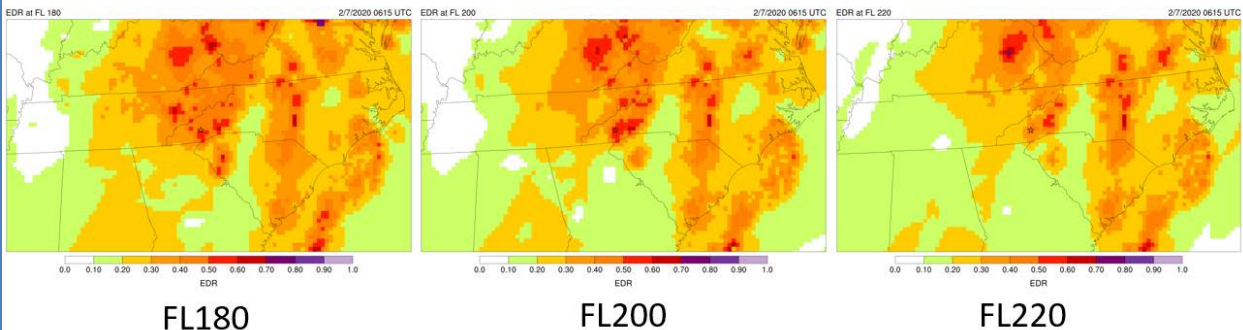


Figure 25 - NCAR GTGN valid for 0115 EST (0615Z) for FL180, FL200, and FL220

NCAR's analysis of the GTGN indicated that the increase in EDR from the GTG to the GTGN can be attributed to the inclusion of the radar based turbulence observations from the NEXRAD

Turbulence Detection Algorithm, which updates every 5-minutes and measures turbulence in the clouds. The GTGN updates from 0045, 0100, and 0115 EST also show the evolution of the convectively induced turbulence over the region.

8.0 NWS Inflight Weather Advisories

Inflight Aviation Weather Advisories are forecasts to advise en route aircraft of development of potentially hazardous weather. Inflight aviation weather advisories in the conterminous U.S. are issued by the NWS AWC, as well as from the Center Weather Service Units (CWSU) associated with FAA ARTCCs. There are four basic types of inflight aviation weather advisories: the Significant Meteorological Information (SIGMET), the Convective SIGMET, the Airmen's Meteorological Information (AIRMET), and the Center Weather Advisory (CWA). Inflight advisories serve to notify en route pilots of the possibility of encountering hazardous flying conditions which may not have been forecast at the time of the preflight briefing. Whether or not the condition described is potentially hazardous to a particular flight is for the pilot and/or aircraft dispatcher to evaluate on the basis of experience and the operational limits of the aircraft.

During the period the Atlanta CWSU was closed; however, they had issued a CWA for moderate to severe turbulence which extended over the accident site hours before the accident. The NWS AWC issued several advisories during the period in the form of SIGMETs and AIRMETs, which impacted the route of flight. Several Convective SIGMETs were also issued during the period for a region east of KCLT which did not impact the route of flight and therefore were not reproduced in this report.

8.1 CWA

The Atlanta CSWU issued CWA number 201 at 1936 EST which was valid until 2130 EST, and was as follows:

*FAUS22 KZTL 070036
ZTL2 CWA 070030
ZTL CWA 201 VALID UNTIL 070230
FROM HNV-60SW PZD-40SW SJI-MSL-HNV
AREA MOD OCNL SEV TB BLW FL180. SEV REPORTED BY CL30 AND PC12. EXP
CONDS TO CONT BYD END OF PD.NO UPDATES EXPECTED AFTER 0215Z*

The advisory warned of an area of moderate to occasional severe turbulence below 18,000 ft (or FL180) and indicated that severe turbulence was reported by a Bombardier Challenger 300 business jet and a Pilatus PC-12 single engine turboprop. The advisory indicated that the conditions were expected to continue beyond the end of the period and indicated that no updates were expected after 2115 EST due to the CWSU operating hours. Figure 26 is the advisory plotted over a satellite image valid at the time of issuance.

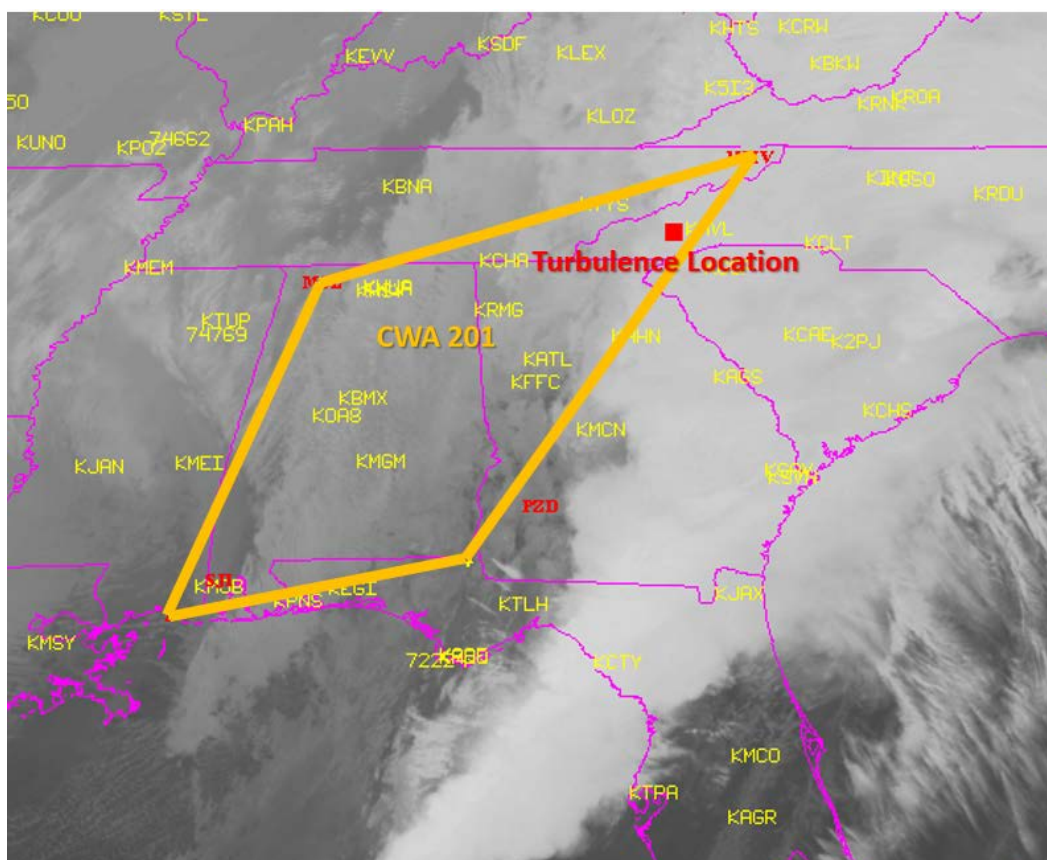


Figure 26 - CWA 201 issued at 1936 EST for severe turbulence

8.2 SIGMETs

The NWS AWC issued SIGMET Xray 1 at 2132 EST and was valid until 0132 EST. The advisory warned of occasional severe turbulence below FL190 due to strong low-level winds and windshear associated with the jet stream. The advisory indicated that the turbulence was also reported by several regional air carrier and business jets over the area. The conditions were expected to continue beyond 0132 EST. The advisory was as follows and is plotted in figure 27.

WSUS02 KPCI 070232
 WS2X
 -MIAX WS 070232
 SIGMET XRAY 1 VALID UNTIL 070632
 NC SC GA FL TN LA MS AL AND CSTL WTRS
 FROM 30NW VXV TO 20ESE GSO TO 160W PIE TO 130ESE LEV TO 50S LEV
 TO 30NW VXV
 OCNL SEV TURB BLW FL190. DUE TO STG LOW LVL WNDG AND WNDSHR
 ASSOCD WITH JTST. RPTD BY CRJ9 C56x. CONDS CONTG BYD 0632Z.

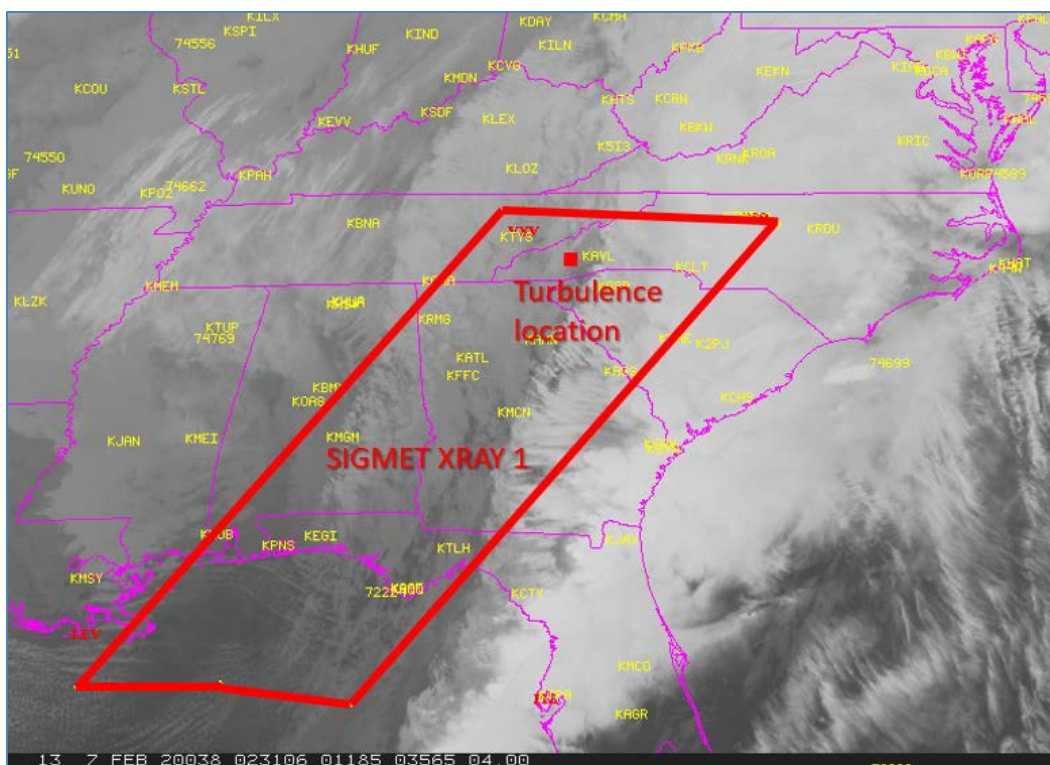
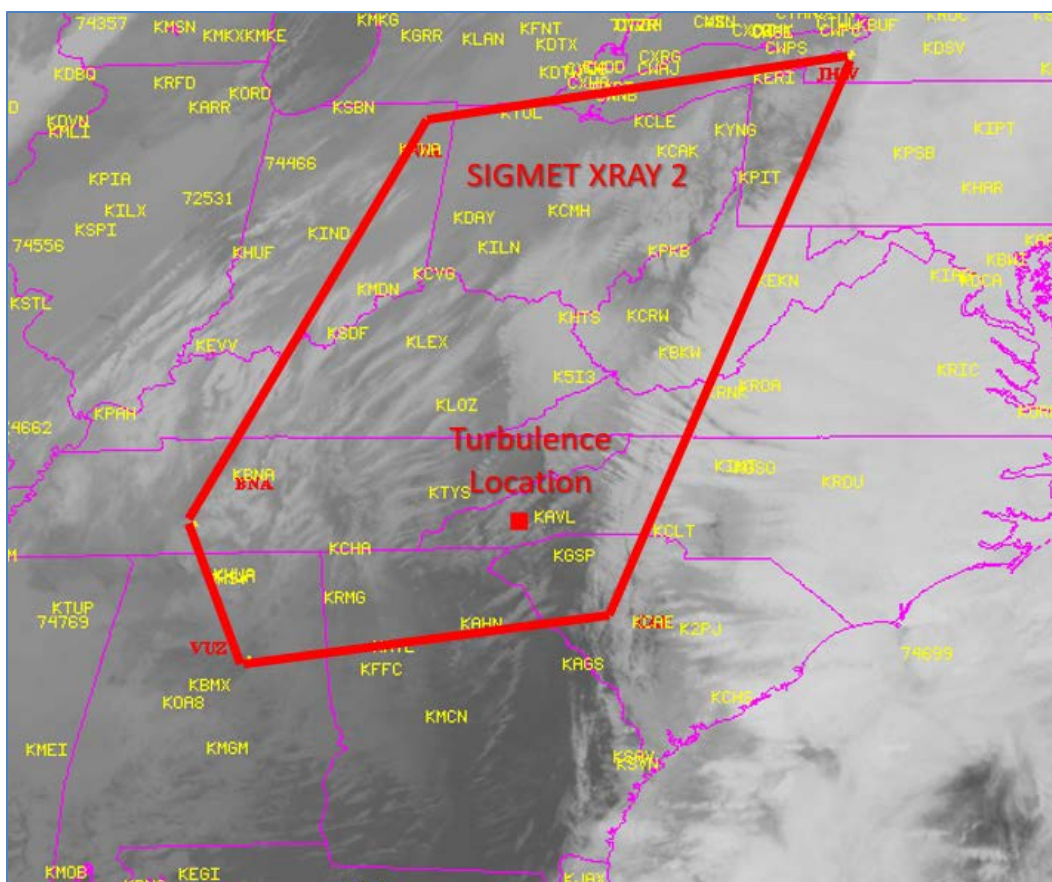


Figure 27 - SIGMET Xray 1 issued 2132 EST and valid until 0132 EST at for severe turbulence

The advisory was updated at 0102 EST by SIGMET Xray 2 which continued to expect occasional severe turbulence over the area between 10,000 ft and 24,000 ft due to strong low-level winds and windshear associated with the jet stream. Figure 28 is the plot of SIGMET XRAY 2 with the turbulence location marked.

WSUS02 KNCI 070602
 WS2X
 -MIAX WS 070602
 SIGMET XRAY 2 VALID UNTIL 071002
 NC SC GA NY PA OH LE WV VA IN KY TN AL
 FROM 20NNE JHW TO 30WNW CAE TO 30ESE VUZ TO 50SW BNA TO 30NNE FWA
 TO 20NNE JHW
 OCNL SEV TURB BTN 100 AND FL240. DUE TO STG LOW LVL WNDZ AND
 WND SHR ASSOCD WITH JTST. RPTD BY ACFT. CONDS CONTG BYD 1002Z.



8.3 AIRMETs

The NWS AWC issued a full series of AIRMETs for IFR and mountain obscuration conditions, moderate turbulence and low-level wind shear, and moderate icing conditions over the route. The advisories are depicted as G-AIRMETs valid for 0100 EST in figures 29-31.

SIERRA 2020-02-07 06:00:00

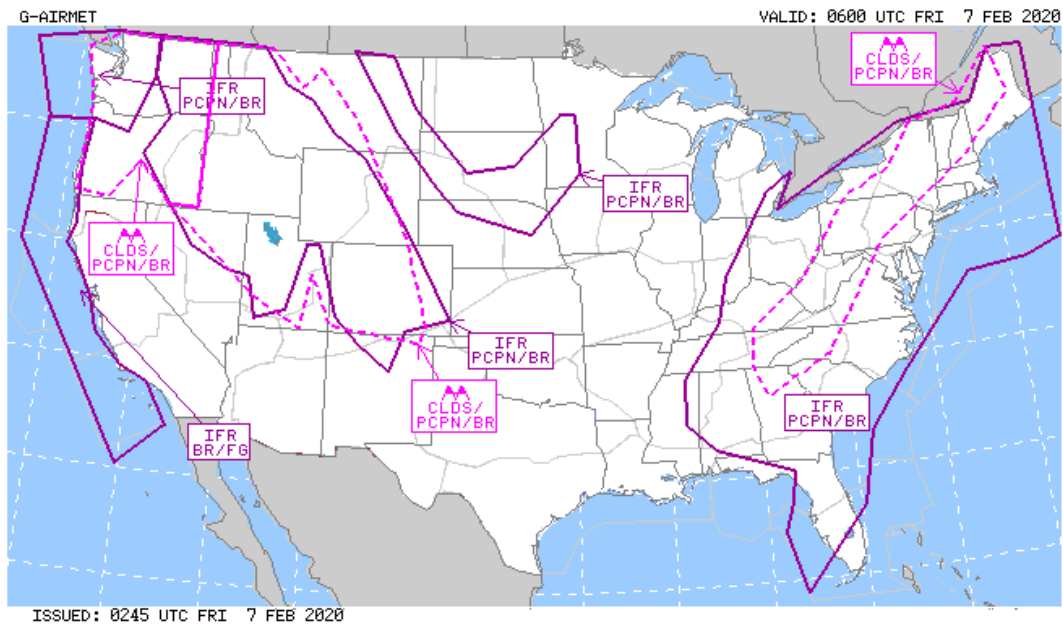


Figure 29 - G-AIRMET Sierra for IFR and mountain obscuration conditions valid for 0100 EST

TANGO 2020-02-07 06:00:00

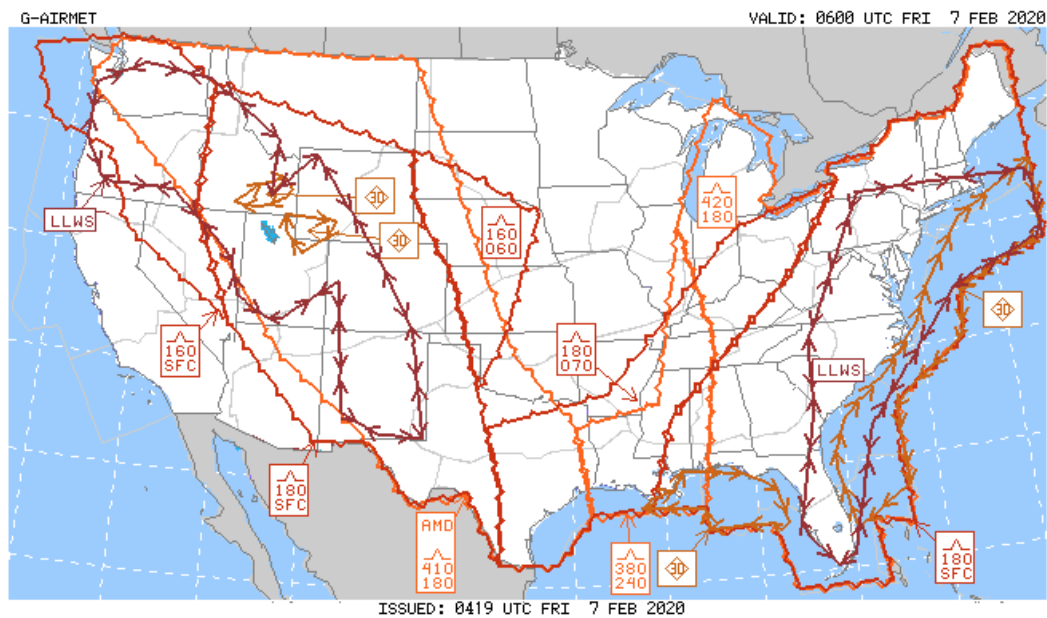


Figure 30 - AIRMET Tango valid for 0100 EST for moderate turbulence and low-level wind shear

ZULU 2020-02-07 06:00:00

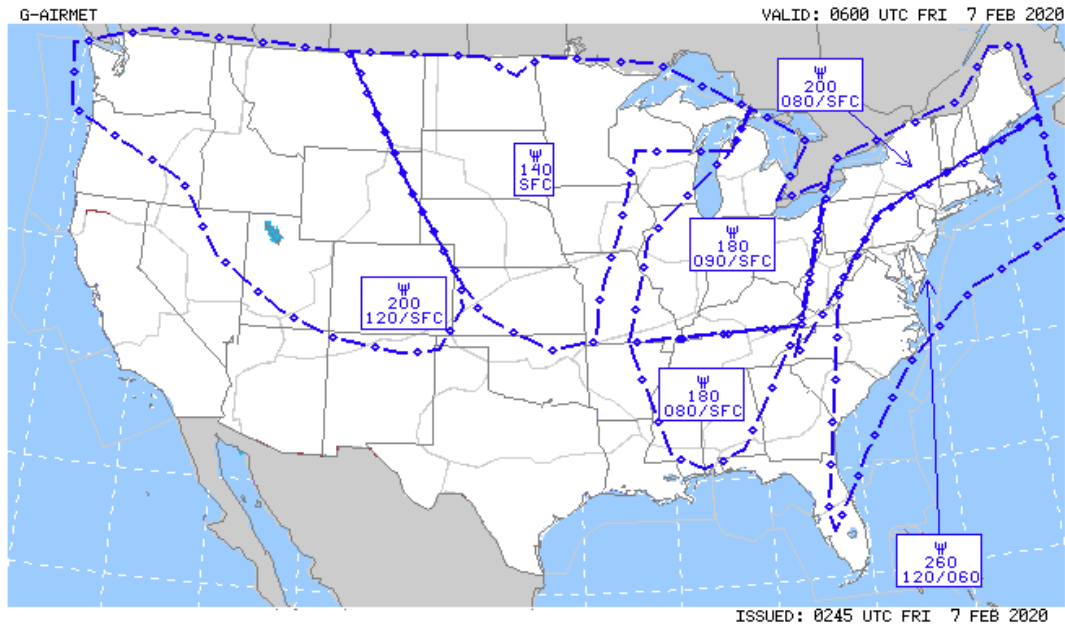


Figure 31 - AIRMET Zulu for moderate icing conditions valid for 0100 EST

9.0 Preflight Weather Briefing

The flight was provided a company generated weather document and flight release at 2338 EST. The dispatch release expected a wet runway at KTYS and included a destination alternate airport of Lovell Field Airport (KCHA), Chattanooga, Tennessee, and added 25 minutes of contingency fuel in addition to the required 45 minute reserve. The flight was planned for a cruising altitude of 22,000 ft direct to KTYS.

The weather document included the METARs, TAFs, NOTAM, and runway condition reports for the departure, destination, and alternate airports, as well as winds and temperature aloft data. In addition, the weather document included several advisories issued by the Enhanced Weather Information System (EWINS) provider “The Weather Company” adverse weather forecasts or SIGMEC’s and NWS Convective SIGMETs. The SIGMECs were as follows and are plotted in figure 32. No NWS CWAs, SIGMETs, or AIRMETs were included in the weather document.

*SIGMEC TURB 61310A
VALID 07FEB20/0227Z - 07FEB20/0600Z
NEUS SEUS
INTST MDT
ALT FL280 - FL350
AREA 25W VWV - 35NW VXV - 40S PSK - 55SSW JHW - 25W VWV
MVT NNE 35KT
OUTLK NC IN INTENSITY
DISC MDT TURBULENCE DUE TO CONV BLOWOFF AND TRANSVERSE BANDI
NG. REPLACES SIGMET 60239. FLIGHT LEVELS LOWER
SLIGHTLY.*

SIGMEC TURB 61438B
VALID 07FEB20/0357Z - 07FEB20/0600Z
SEUS
INTST MDT - OCNL SVR
ALT FL60 - FL180
AREA 65WSW VXV - 45ESE VUZ - 25S MCN - 35SW SPA - 65WSW VXV -
MVT NE 25KT
OUTLK NC IN INTENSITY
DISC OCNL SVR TURBC OVER GA ALONG STRONG MIDLEVEL JET BEHIND
FRNTL BNDRY.

SIGMEC TURB 61466A
VALID 07FEB20/0426Z - 07FEB20/0900Z
NEUS SEUS
INTST MDT
ALT FL80 - FL180
AREA 55WSW VXV - 35SW SPA - 15NNE DCA - 70WSW PSB -55WSW VXV -
MVT NE 35KT
OUTLK NC IN INTENSITY
DISC MDT TURBC OVER WRN NC INTO WV ALONG STRONG MIDLEVEL JET
. REPLACES SIGMET 61236.

SIGMEC TURB 61463A
VALID 07FEB20/0500Z - 07FEB20/0800Z
SEUS WATL
INTST MDT - OCNL SVR
ALT FL280 - FL370
AREA 70NW TAY - 30NE CRG - 55NE FLO - 15NW CLT -70NW TAY -
MVT NE 35KT
OUTLK NC IN INTENSITY
DISC OCNL SVR TURBC ALONG BACKSIDE OF CONVECTION OVER SC/GA.
REPLACES SIGMET 61342.

Of the advisories issued to the flight only one SIGMEC #61466A extended over the accident or turbulence location. That advisory warned of moderate turbulence between 8,000 ft through 18,000 ft. The advisory was valid through 0400 EST and expected to continue and move towards the northeast at 35 knots. The discussion indicated that moderate turbulence was associated along a strong mid-level jet stream.

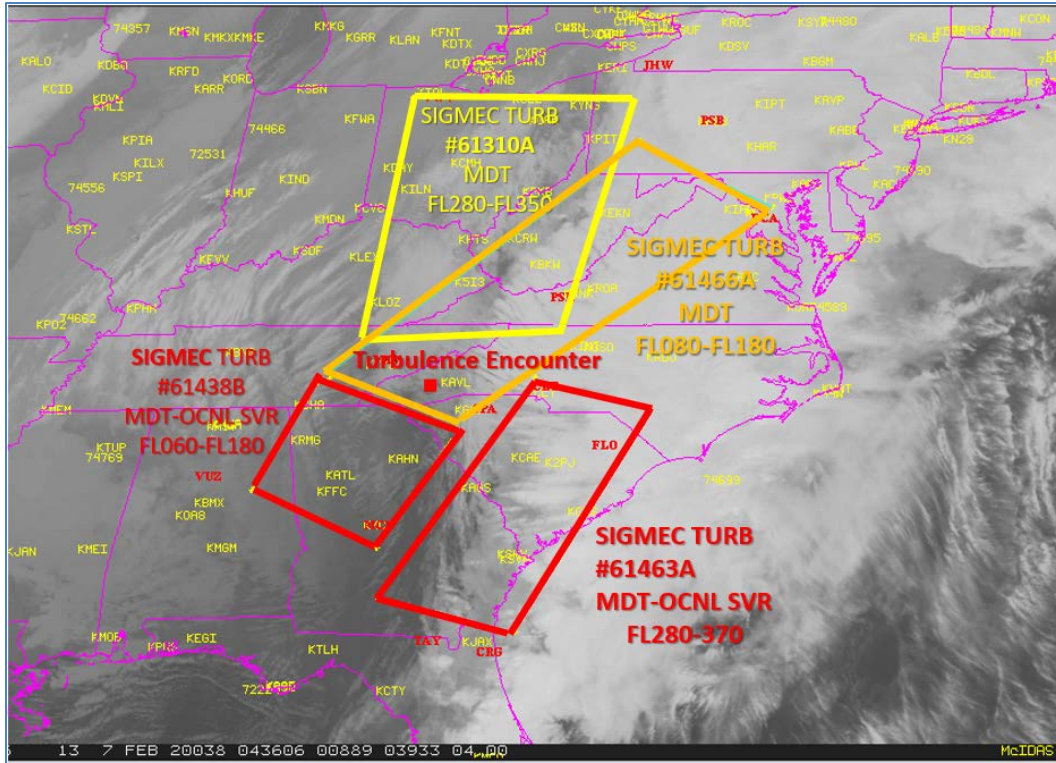


Figure 32 - Weather Company issued SIGMEC's issued to flight

10.0 Astronomical Conditions

The astronomical conditions were obtained from the United States Naval Observatory (USNO) Multiyear Interactive Computer Almanac software data for Charlotte, South Carolina. The time of the accident has been added for reference in **italic bold type**.

Sun

Sunset	1756 EST February 6, 2020
End civil twilight	1822 EST

Moon

Rise	1615 EST February 6, 2010
Moon Culmination	2338 EST

<i>Accident</i>	<i>0105 EST February 7, 2020</i>
Moonset	0604 EST February 7, 2020

At the time of the turbulence event the Sun was more than 15° below the horizon and official nighttime prevailed. The Moon's altitude was 56° above the horizon at an azimuth of 257°, with the 94% of the Moon's disk illuminated with the phase a waxing gibbous.

F. LIST OF ATTACHMENTS

Attachment 1 - NCAR GTG and GTGN comparison for the period

Attachment 2 - Flight Release and Weather document issued to flight

Submitted by:

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