

National Transportation Safety Board

Office of Aviation Safety

Washington, DC 20594



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METEOROLOGY

Specialist's Factual Report

December 9, 2024

TABLE OF CONTENTS

A. ACCIDENT	3
B. METEOROLOGY SPECIALIST	3
C. SUMMARY	3
D. DETAILS OF THE INVESTIGATION	3
E. FACTUAL INFORMATION	4
1.0 SYNOPTIC CONDITIONS	4
1.1 Surface Analysis Chart.....	4
1.2 12-hour Surface Prognostic Chart	5
1.3 Regional Composite Radar Mosaic	6
2.0 SURFACE OBSERVATIONS	7
2.1 Atlanta, Georgia	7
2.2 Lawrenceville, Georgia.....	8
2.3 NWS METAR Regional Display.....	9
3.0 PILOT REPORTS	10
4.0 SOUNDING.....	11
5.0 SATELLITE IMAGERY	14
6.0 WEATHER RADAR IMAGERY	16
6.1 Composite Reflectivity Imagery	17
6.2 Base Reflectivity Imagery	22
6.3 Radar Cross Section.....	25
6.4 FAA Consolidated Storm Prediction for Aviation Display	27
7.0 NWS FORECASTS	31
7.1 Convective Outlook.....	31
7.2 Terminal Aerodrome Forecast.....	33
7.3 Area Forecast Discussion.....	34
8.0 NWS INFLIGHT WEATHER ADVISORIES	36
9.0 GRAPHIC TURBULENCE GUIDANCE NOWCAST	37
10.0 TURBULENCE REFERENCE MATERIAL	38
F. LIST OF ATTACHMENTS	40

A. ACCIDENT

Location: Atlanta, Georgia
Date: August 29, 2023
Time: 1831 eastern daylight time (EDT)
2231 universal coordinated time (UTC)
Airplane: Airbus A350-941, Delta Air Lines flight 175; Registration: N579DZ

B. METEOROLOGY SPECIALIST

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C. SUMMARY

On August 29, 2023, about 1831 eastern daylight time, Delta Air Lines (DAL) flight 175, an Airbus A350-941, encountered convective turbulence during descent into Hartsfield Jackson International Airport (ATL), Atlanta, Georgia. Of the 14 crew and 151 passengers onboard, 2 crew and 2 passengers sustained serious injuries, and 8 crew and 5 passengers sustained minor injuries. The aircraft sustained minor damage. DAL175 was a 14 *Code of Federal Regulations (CFR)* Part 121 scheduled international passenger flight from Milan Malpensa Airport (MXP), Milan, Italy to ATL.

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 remotely, collecting data from official National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS) sources including the Weather Prediction Center (WPC), and the National Center for Environmental Information (NCEI). This report documents the general weather products and forecasts over the region during the period and documents the pertinent meteorological parameters to the accident. All times are reported as eastern daylight time (EDT) based upon the 24-hour clock, local time is -4 hours from UTC, and UTC=Z. Airport and NWS 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. continental 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 estimated at latitude 34.095633° North and longitude 83.834486° West at approximately 15,100 ft based on data from the Flight Data Recorder (FDR).

E. FACTUAL 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 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 and other products can be found in the Federal Aviation Administration (FAA) "Aviation Weather Handbook", FAA-H-8083-28¹.

1.1 Surface Analysis Chart

The southeast section of the NWS Surface Analysis Chart for 1700 EDT² is included as figure 1 with the approximate turbulence location marked by a red star. The chart depicted a stationary front extending from West Virginia southwestward through Kentucky, Tennessee, into northwestern Alabama and eastern Mississippi. Hurricane Idalia was depicted in the Gulf of Mexico off the Florida Gulf Coast with a central pressure of 972-hectopascals (hPa)³, and was located well south of the turbulence event. Hurricane Frankin, in the central Atlantic Ocean, was also depicted on the chart and was forecast to move away from the U.S. coastline. The Atlanta area and turbulence location were located east of the stationary front and in an area of a relatively weak pressure gradient. The station models surrounding the accident site depicted light easterly winds of 5 knots or less, scattered clouds with several stations south of the Atlanta area reporting thunderstorms and rain showers, with broken to overcast sky cover. The closest station model to the accident site depicted a temperature of 89° Fahrenheit (F), with a dew point temperature of 72° F.

¹ <https://www.faa.gov/regulationspolicies/handbooksmanuals/aviation/faa-h-8083-28-aviation-weather-handbook>

² Surface Analysis Charts are created every 3-hours, the chart used was for the analysis about an hour after the event.

³ Hectopascal (hPa) is the standard unit for reporting pressure and is interchangeable with the former term millibar (mb) with the same units. The International Standard Atmosphere (ISA) is based on a sea-level pressure of 1013.25-hPa (29.92 inches of mercury) at 15° Celsius (C) (or 59° F).

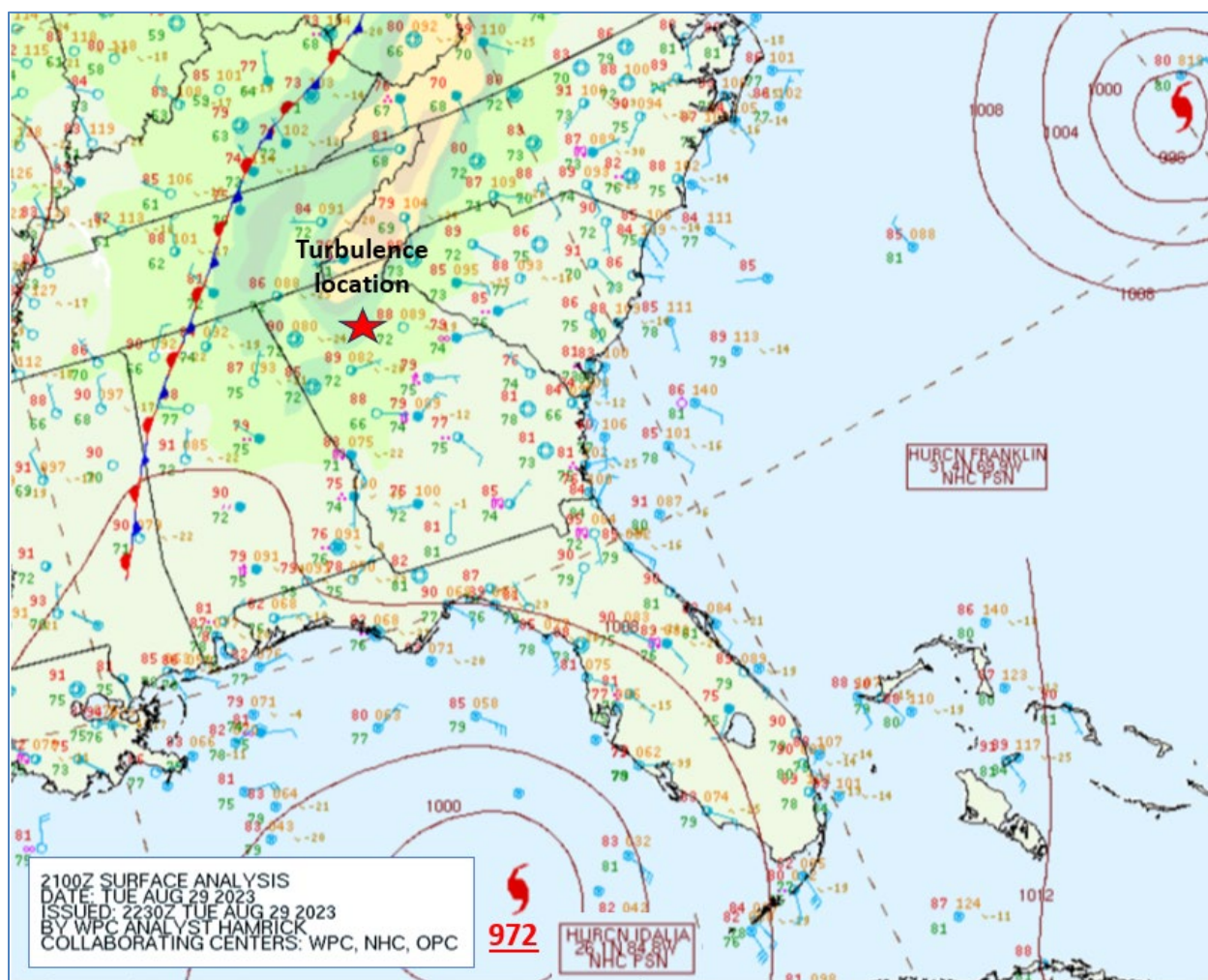


Figure 1 - Southeast section of the NWS Surface Analysis Chart for 1700 EDT with turbulence site.

1.2 12-hour Surface Prognostic Chart

The NCEP 12-hour Surface Prognostic Chart valid for 2000 EDT is included as figure 2. The chart continued to depict the stationary front west of the area stretching from Louisiana northeastward through Pennsylvania. A new feature was added with a trough extending from Mississippi northward through central Georgia into the South and North Carolina and into Virginia. Rain and thunderstorms were expected along and east of the stationary front along the entire eastern United States with rain likely⁴ over Georgia with a chance of thunderstorms. Hurricane Idalia was also depicted moving closer to the northwest Florida gulf coast with a strong pressure gradient over extreme southern Georgia and northwestern Florida.

⁴ Likely is defined as a 60 to 70% chance of occurrence.

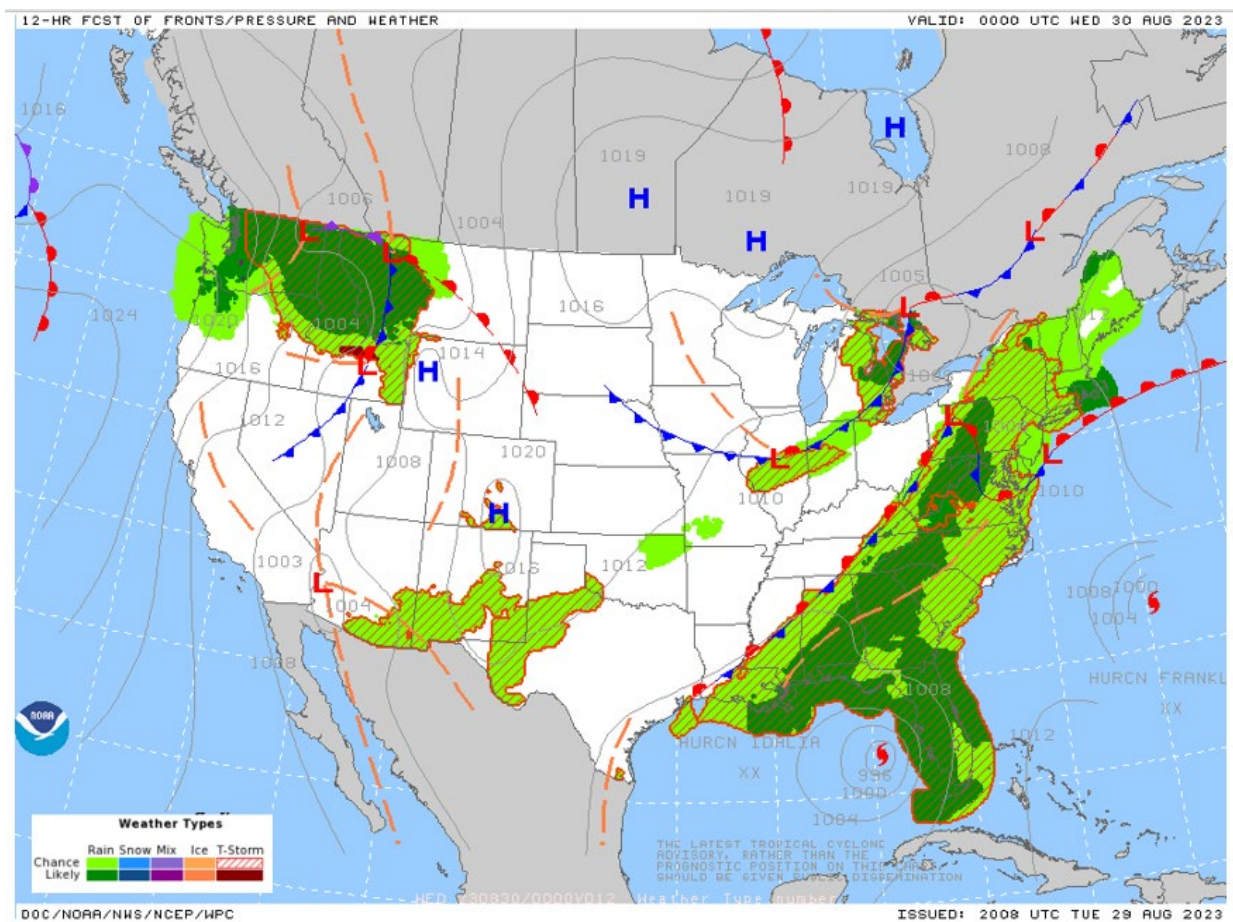


Figure 2 - NWS 12-hour Surface Prognostic chart valid for 2000 EDT.

1.3 Regional Composite Radar Mosaic

The NWS Composite Radar Mosaic for 1830 EDT with the approximate turbulence location marked by a red star is included as figure 3. The chart depicted numerous echoes associated with heavy to extreme precipitation over South Carolina, central Georgia, and into Alabama. The echoes were predominately east, through south and west of the turbulence location. The turbulence location was noted between two areas of echoes, with echoes greater than extreme intensity about 30 miles south-southwest of the turbulence location.

Based on the closeness of the potential echoes and the aircraft's flight path, the local weather surveillance radar will be documented in detail in section 6.0 of this report.

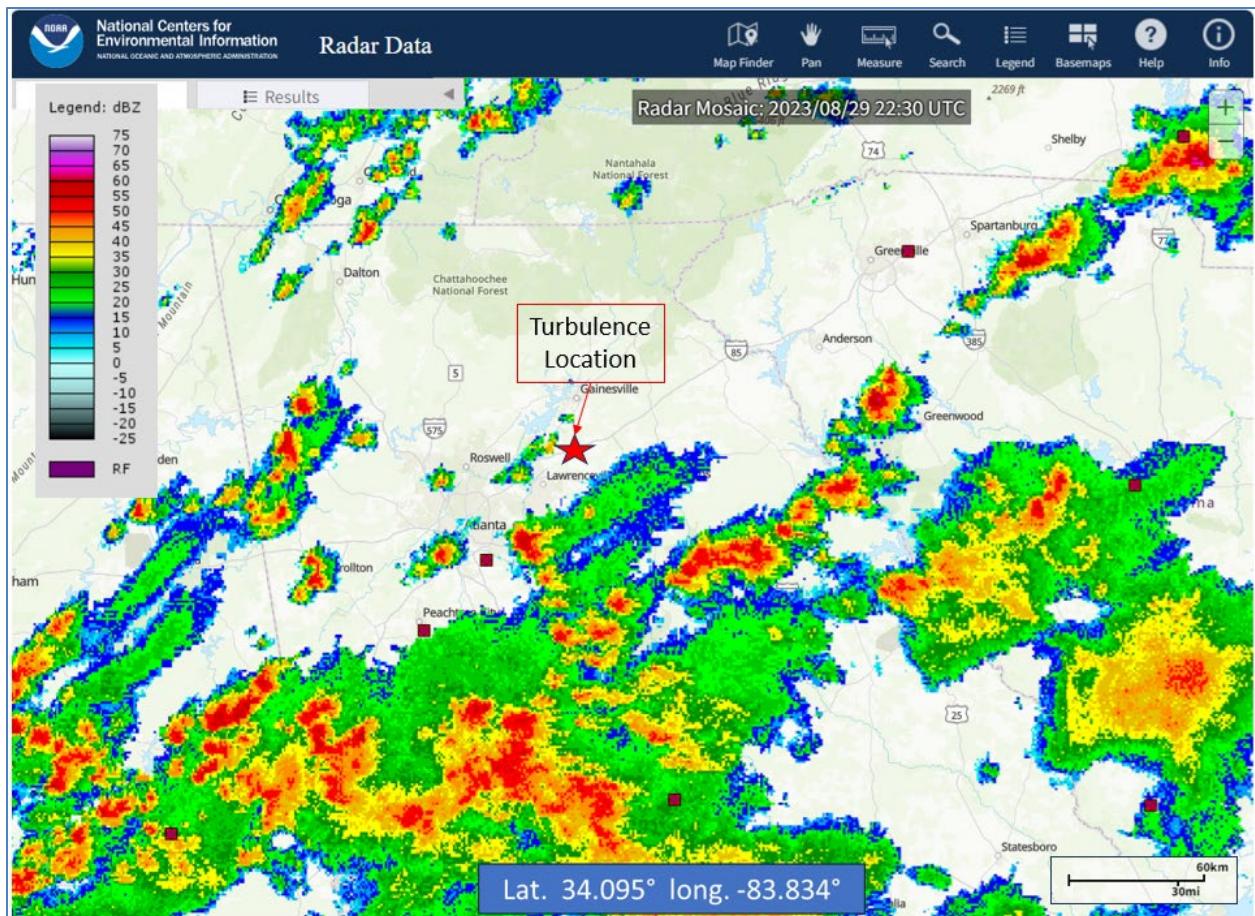


Figure 3 - NWS Composite Reflectivity Mosaic for 1830 EDT with the turbulence location noted.

2.0 Surface Observations

The closest reporting station and destination airport was documented using official Aviation Routine Weather Reports (METAR⁵) and Aviation Selected Special Weather Reports (SPECI). Cloud heights are reported above ground level (agl) in the following section.

2.1 Atlanta, Georgia

The destination airport of Hartsfield-Jackson Atlanta International Airport (KATL), Atlanta, GA, was located about 47 miles southwest of the turbulence location at an elevation of 1,026 ft. The airport had a federally installed and maintained Automated Surface Observation System (ASOS) and was augmented by certified weather observers. At the time of the accident the following conditions were reported.

⁵ Abbreviation for Meteorological Aerodrome Report.

KATL weather observation at 2152Z, wind from 160° at 12 knots gusting to 19 knots, visibility 10 miles or more, scattered clouds at 4,000 ft agl in towering cumulus clouds, ceiling broken at 7,000 ft, broken at 20,000 ft, and broken at 25,000 ft, temperature 31° Celsius (C), dew point temperature 22°C, altimeter 29.82 inches of mercury. Remarks: automated station with a precipitation discriminator, lightning detected distant⁶ east and southeast, sea-level pressure 1008.6-hPa, cumulonimbus clouds distant east, southeast through south, towering cumulus clouds east through overhead and west in all quadrants, temperature 30.6°C, dew point 22.2°C, maintenance indicator on (\$).

The general flight categories⁷ and raw observations surrounding the period from 1652 through 1930 EDT were as follows:

VFR METAR KATL 292052Z 09005KT 10SM FEW040TCU SCT070 SCT200 BKN250 32/22 A2981 RMK AO2 LTG DSNT SE-SW SLP082 CB DSNT SE-SW TCU SW DSNT N-NE NW T03170222 57026 \$

VFR METAR KATL 292152Z 16012G19KT 10SM SCT040TCU BKN070 BKN200 BKN250 31/22 A2982 RMK AO2 LTG DSNT E AND SE SLP086 CB DSNT E SE-S TCU E-OHD-W ALQDS T03060222 \$

Accident 2232Z

VFR METAR KATL 292252Z 16005KT 10SM FEW038CB SCT055 BKN110 OVC200 28/21 A2983 RMK AO2 LTG DSNT NE AND E SLP089 RAB14E24 CB W-NW DSNT NE-SE MOV N TCU NW-NE P0000 T02830206 \$

VFR SPECI KATL 292301Z 16005KT 10SM TS FEW035CB SCT060 BKN100 OVC200 28/21 A2983 RMK AO2 TSB01 OCNL LTGICCG VC N-NE TS VC N-NE MOV N TCU W-N NE T02780206 \$

2.2 Lawrenceville, Georgia

Gwinnett County Airport-Briscoe Field (KLZU), Lawrenceville, GA, was located about 5 miles southwest of the accident location at an elevation of 1,062 ft. The airport had an Automated Weather Observation System (AWOS), which was augmented by

⁶ Distant - is defined as beyond 10 nautical miles from the station, but less than 30 miles.

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

- 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.

certified air traffic controllers⁸. The following conditions were reported at the approximate time of the accident.

KLZU weather observation at 1756 EDT, wind variable at 5 knots, visibility 10 miles or more, ceiling broken at 4,000 ft, temperature 31° C, dew point temperature 24° C, altimeter 29.84 inHg. Remarks: automated station with a precipitation discriminator, lightning detected distant south and southwest, sea-level pressure 1010.3-hPa, temperature 30.6° C, dew point 23.9° C.

The general flight category and raw observations reported surrounding the period from 1656 through 1900 EDT were as follows.

MVFR METAR KLZU 292056Z 08004KT 10SM BKN028 31/23 A2983 RMK AO2 SLP099 T03060233 56027=

VFR SPECI KLZU 292103Z 11006KT 10SM CLR 31/23 A2983 RMK AO2=

VFR **METAR KLZU 292156Z VRB05KT 10SM BKN040 31/24 A2984 RMK AO2 LTG DSNT S AND SW SLP103 T03060239=**

VFR METAR KLZU 292256Z 12007KT 10SM VCTS CLR 29/24 A2983 RMK AO2 LTG DSNT S AND SW TSB51 SLP100 T02890239=

2.3 NWS METAR Regional Display

A depiction of the observations and the general flight conditions surrounding the approximate time of the accident from the NWS Aviation Weather Center's (AWC) METAR website⁹ is included as figure 4. The approximate turbulence location is marked by a red star and the position of the plotted pilot report¹⁰ of severe turbulence as received by the NWS. The regional radar reflectivity of the 0.5° base reflectivity image is also overlaid on the image.

⁸ Limited Aviation Weather Reporting Station (LAWRS) - An airport weather station that utilized various degrees of automated sensors and/or other automated equipment (ie; AWOS) and is often augmented/backed up by certified tower weather observers at these locations.

⁹ <https://www.aviationweather.gov/metar>

¹⁰ The actual location of the turbulence encounter and the reported position often are different due to delay in reporting, referencing the position, and reporting the encounter to air traffic control or flight dispatch, which can enter the formal pilot report (PIREP).

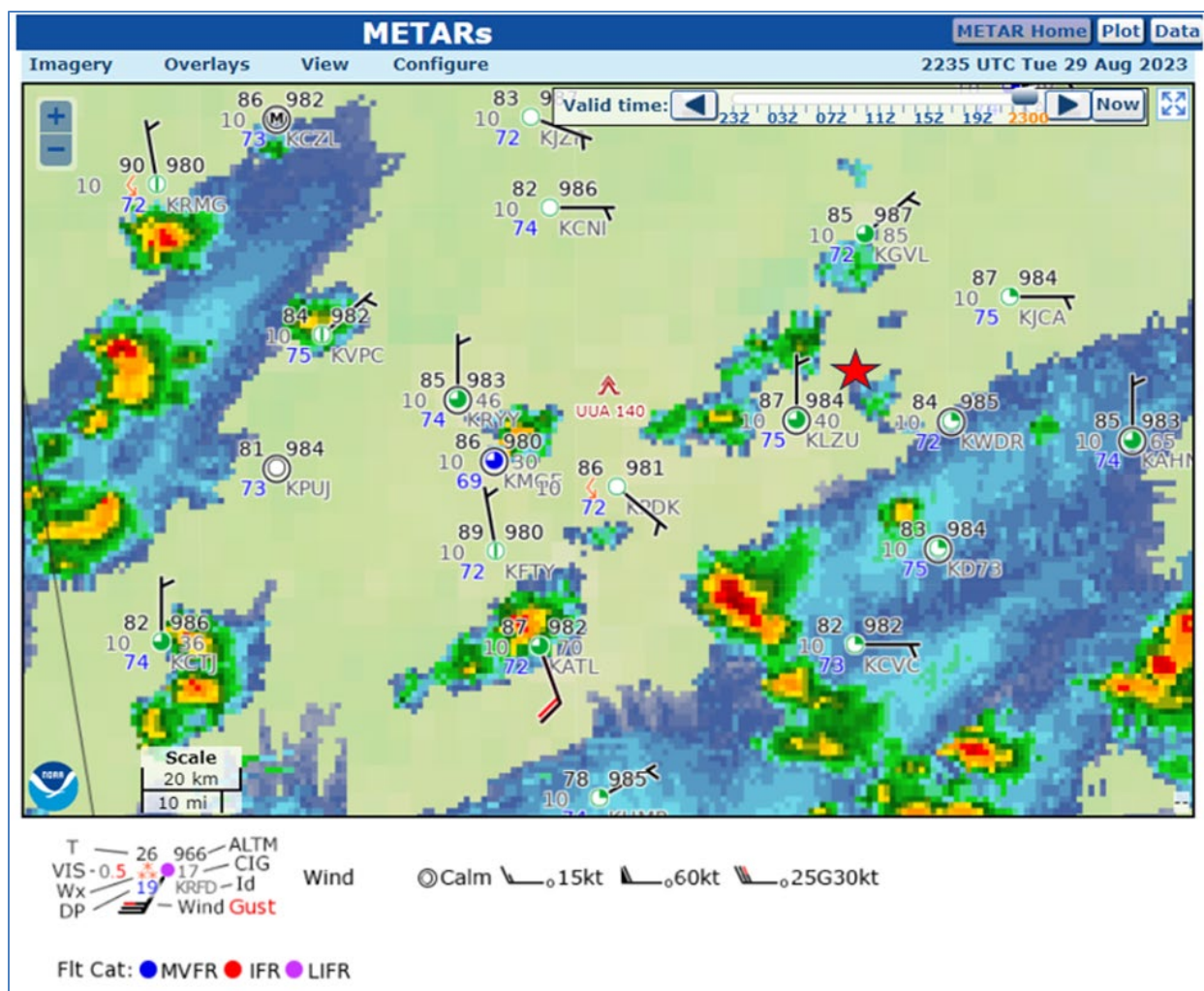


Figure 4 - NWS Aviation Weather Center's METAR display for 1835 EDT centered over the area with the regional radar reflectivity.

3.0 Pilot Reports

The following pilot reports or PIREPs were reported¹¹ within 150 miles of the Atlanta from 1630 through 1930 EDT, with the reports only over Georgia included below. The accident airplane's report is highlighted in bold type. The altitudes are provided by Flight Levels (FL), which is reference to pressure altitude in hundreds of feet.

ABY UA /OV ABY090030/TM 2030/FL220/TP CRJ9/TB CONS LGT OCNL MOD

AHN UA /OV AHN185015/TM 2043/FL150/TP E55P/SK SKC/TB NEG/IC NEG/RM ZTLFD

TOC UA /OV ODF355010/TM 2045/FL160/TP F16/SK SKC/TB NEG/IC NEG/RM ZTLFD

¹¹ Includes PIREPs disseminated longline and may not include "ride reports" or other reports made on radio frequency to air traffic control.

AGS UA /OV IRQ180020/TM 2058/FL330/TP E170/TB CONS MOD/RM ZTLFD

ATL UA /OV ATL120040/TM 2104/FL250/TP FA20/WX VMX/TB NEG/RM SMOOTH DURC ZTLFD

WRB UA /OV VNA270028/TM 2118/FL240/TP LJ60/TB CONS MOD CHOP 240-110/RM DURD ZTLFD

ABY UA /OV ABY010030/TM 2118/FL170/TP LJ60/WX TS/TB LGT-MOD

ATL UA /OV ATL085040/TM 2151/FL150/TP A320/TB NEG/RM ZTLFD

AHN UA /OV AHN140030/TM 2213/FL380/TP MD11/SK TOP390/WX TS/RM ZTLFD

ATL UA /OV AUO180005/TM 2213/FL090/TP SR22/SK SCT040

AGS UA /OV IRQ250025/TM 2220/FL210/TP B712/TB CONS MOD CAT/RM ZTLFD

LGC UA /OV LGC270025/TM 2229/FL270/TP BE20/TA M16/TB LGT-MOD CAT/IC LGT-MOD MX/RM
ZTLFD

ATL UUA /OV ATL022021/TM 2235/FL140/TP A359/TB SEV/RM INJURIES REPORTED ON BOARD

AHN UA /OV AHN325010/TM 2314/FL150/TP A333/TB NEG/RM ZTLFD

AMG UA /OV AMG334021/TM 2320/FL080/TP BE58/SK BASE090/TB NEG/RM VMC SMOOTH AND
CLEAR

PDK UA /OV PDK030003/TM 2353/FLDURGD/TP C560/RM + OR - 15K WIND SHEAR

Of the 12 PIREPs recorded over Georgia prior to the event, there were 5 reports of light to occasional moderate turbulence above FL180, with 2 reports below 18,000 ft. There were also 2 reports of thunderstorms with one with turbulence associated with it. There were no urgent reports until the accident airplane's severe report at 1835 EDT (2235Z).

4.0 Sounding

A High Resolution Rapid Refresh (HRRR) numerical model¹² data was obtained from the NOAA Air Resource Laboratory for 1800 EDT for the closest grid point¹³ to the turbulence location. The data was then plotted on a standard Skew T log P diagram¹⁴

¹² The HRRR is a NOAA real-time three-kilometer resolution, hourly-updated, cloud-resolving, convection-allowing atmospheric model, initialized by three-kilometer grids with three-kilometer radar assimilation. Radar data is assimilated in the HRRR every 15 minutes over a one-hour period.

¹³ Grid point used was by the HRRR was latitude 34.08°N and longitude 83.85°W.

¹⁴ 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.

RAOB: ARL HERR 2200Z SOUNDING OVER TUBE GRID.TXT / YR: 2023 MON: 08 DAY: 29 HOUR: 22 (Tue) 29 Aug 10:00 PM

hPa 450

Cloud (% caps) CAT

500

600

700

800

900

1000

1050

0 10 20 30 40 50 °C

Strn Elev: 951 ft
QNH = 1011.0 hPa
DA: 3238 ft, ISA

TROP Lvl: -- ft AGL
PRZG Lvl: 14640 ft AGL
CCL Lvl: 27709 ft AGL
LFC Lvl: 41900 ft AGL
LCL Lvl: 3223 ft AGL
CCL Lvl: 4022 ft AGL
LCL Lvl: 3153 ft AGL
Water: 1.91 in
Hail: 0.25 in
TSGust: 48 mph
WindDir: 55 mph
SWHAT: 204.2
CAP: 0.3
LI: -5.3
TT: 46.1
KI: 25.0
Tc: 30.2 °C

Storm: 270/5 0-6km
s-rH: 19 0-2km
s-rH: 15 0-2km
s-rH: 5 0-1km

CAPE+ only: 1781 J/kg
CIN total: -1 J/kg
DCAPE: 6.0km: 620 J/kg
VGP 0-6km: 0.108
EHI 0-2km: .2
MVV: 60 m/s
EBN: 160

LFC Lvl / LCL 977 hPa

0 10 20 30 40 50 °C

MSL

KNOTS

The HRRR sounding depicted a near surface temperature of 29°C (86°F), a dew point temperature of 22°C (72°F), with a relative humidity of 64%. The lifted condensation level (LCL)¹⁶ was identified at 3,153 ft agl, the level of free convection (LFC)¹⁷ at 3,323 ft agl, and the convective condensation level (CCL)¹⁸ at 4,022 ft agl.

¹⁸ Convective Condensation Level (CCL) - the height at which a parcel of air, when heated sufficiently

The equilibrium level (LFC-EL)¹⁹ or expected cloud tops of the convection was estimated to 41,900 ft. The precipitable water content was 1.91 inches. The sounding depicted a general moist and unstable atmosphere with a Lifted Index (LI)²⁰ of -5, a K-index²¹ of 35, a Convective Available Potential Energy (CAPE)²² value of 1,781 J/kg (red shaded area), and supported strong updrafts near 60 m/s. The sounding wind profile indicated surface winds from the southeast which veered²³ to the west with height with slowly increasing wind speeds. At 14,600 ft the sounding depicted a wind from 245° at 12 knots. The freezing level was at about 16,000 ft.

A table of the HRRR sounding parameters of height, pressure, temperature (T), dew point temperature (Td), relative humidity (RH), wind direction and speed, and the RAOB derived clear air turbulence (CAT), Low-Level Wind Shear (LLWS), and Icing potential through 20,000 ft is included below.

Height (ft-msl)	Pres (hPa)	T (°C)	Td (°C)	RH (%)	Wind (dir kts)	CAT (FAA)	LLWS (FAA)	Icing (USAF)
951	977	29.5	22.0	64	130/ 4			
981	976	29.4	21.4	62	130/ 4			
1071	973	29.1	21.9	65	130/ 4			
1222	968	28.6	20.9	63	130/ 5			
1495	959	27.8	20.7	65	135/ 5			
1893	946	26.6	20.3	68	135/ 5			
2481	927	24.9	20.0	74	140/ 5			
3110	907	23.0	19.3	80	140/ 5			
3845	884	21.2	17.6	80	150/ 5			
4627	860	19.0	16.4	85	155/ 5		LGT	

from below, rises and becomes saturated. It is where newly forming convective clouds should form bases.

¹⁹ Equilibrium Level (EL) - the level where the lifted parcel again equals the environmental temperature, working upward from the LFC. The EL represents the top of the layer containing CAPE and the height at which thunderstorm updrafts no longer accelerate upward. Thus, to a close approximation, it represents the height of expected thunderstorm tops. However, strong updrafts will continue to rise past the EL before stopping, resulting in storm tops that are higher than the EL. This process sometimes can be seen visually as an overshooting tops or anvil dome on weather satellite imagery.

²⁰ Lifted Index (LI) - A common measure of atmospheric instability. Its value is obtained by computing the temperature that air near the ground would have if it were lifted to 500-hPa or approximately 18,000 feet and comparing that temperature to the actual temperature at that level. Positive values indicate a stable atmosphere, while negative numbers indicate instability.

²¹ K-Index - The measure of thunderstorm potential based on the vertical temperature lapse rate, the moisture content of the lower atmosphere and the vertical extent of the moist layer. The higher the K-Index value the greater the probability of air mass type thunderstorm development across the region. A K-index of 35 indicated an airmass thunderstorm probability of near 80%.

²² Convective Available Potential Energy (CAPE) is a measure of the amount of energy available for convection. CAPE is directly related to the maximum potential vertical speed within an updraft; thus, higher values indicate greater potential for severe weather.

²³ Veering refers to the clockwise rotation of the wind with height and is typically associated with warm air advection.

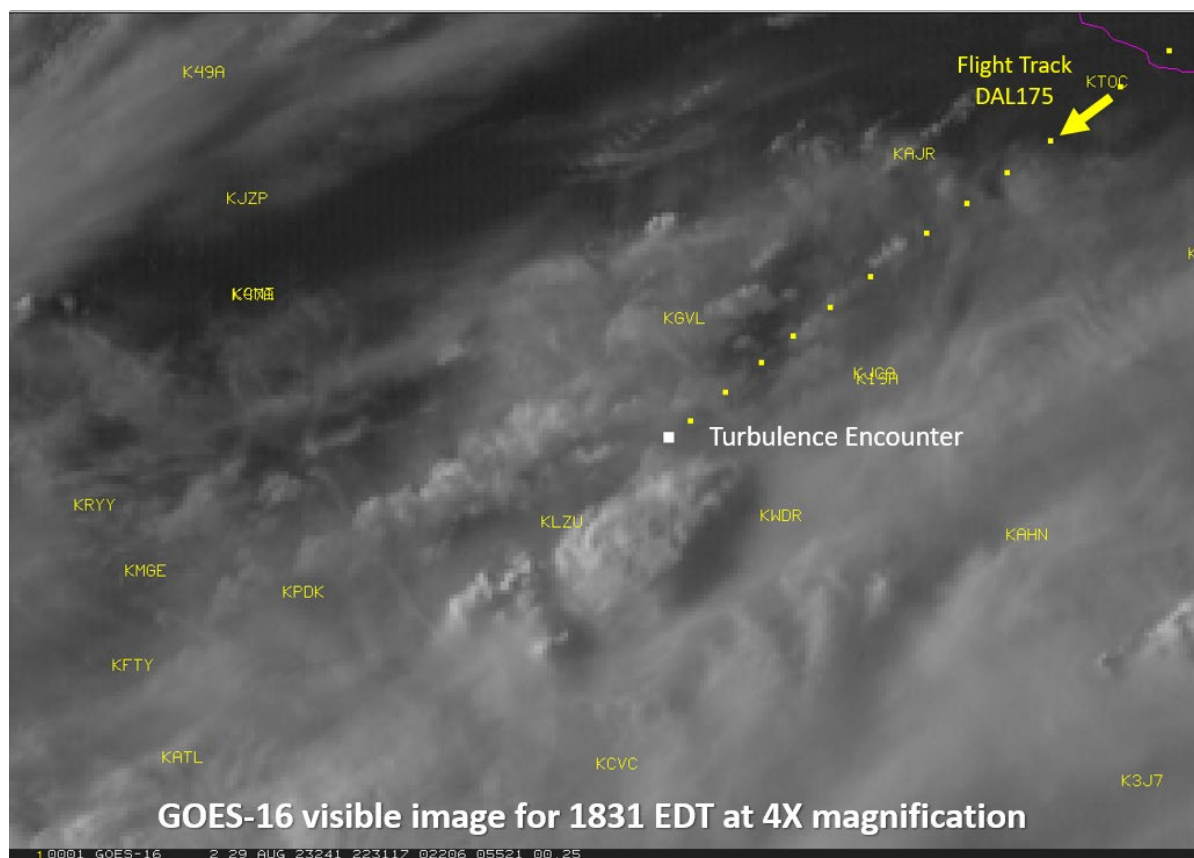
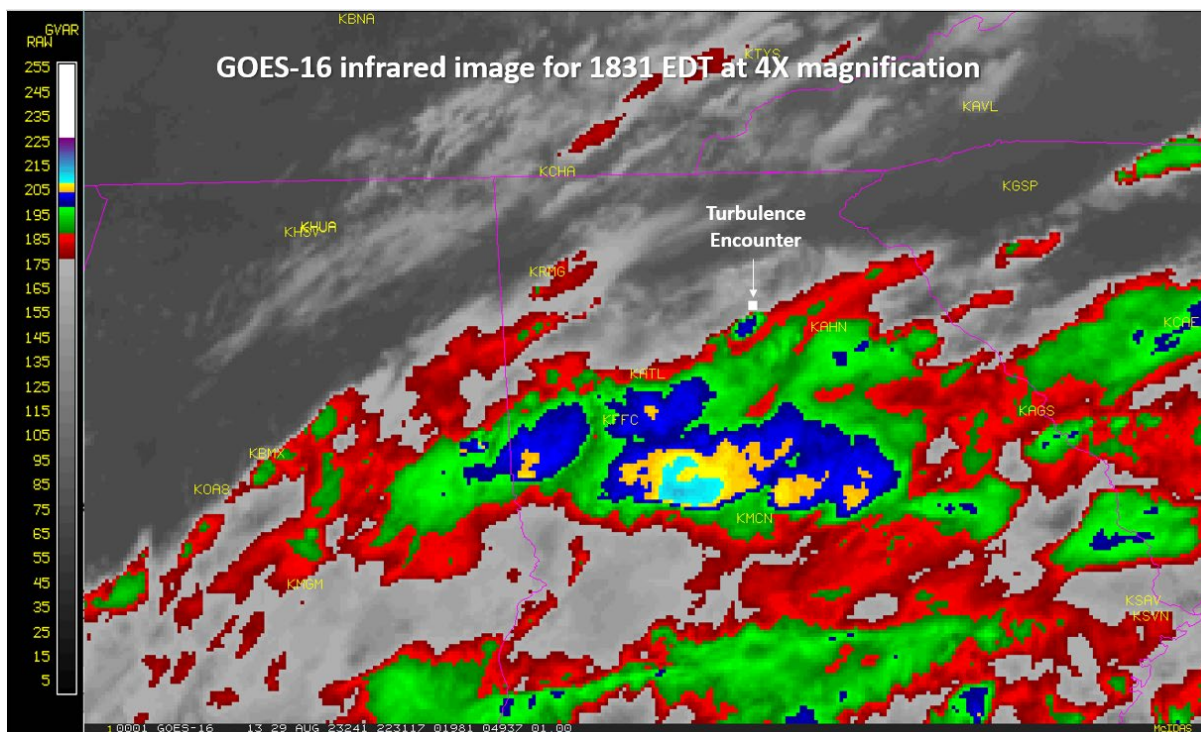
5560	832	17.1	14.0	82	190/ 5	LGT
6553	803	15.2	11.3	78	230/ 6	
7718	770	13.0	8.6	75	230/ 8	
9036	734	10.5	5.9	73	230/ 9	
10485	696	7.9	2.9	71	240/ 10	
12124	655	5.7	-1.8	58	245/ 11	
13983	611	2.8	-3.5	63	245/ 12	
16051	565	-0.8	-5.6	70	260/ 11	
18215	520	-4.3	-8.5	72	265/ 7	
20326	479	-8.1	-13.5	65	275/ 7	LGT

5.0 Satellite Imagery

NOAA Geostationary Operational Environmental Satellite number 16 (GOES-16) infrared and visible imagery were obtained from an archive at the Space Science Engineering Center (SSEC) at the University of Wisconsin-Madison in Madison, Wisconsin, and processed using the Man-computer Interactive Data Access System (McIDAS) software. The infrared band 13 at a wavelength of 10.3 microns (μm) provided a resolution of 2 kilometers (km) with radiative cloud top temperatures, and the visible band 2 imagery at a wavelength of 0.64 μm provided a resolution of 0.5 km.

Figure 6 is the GOES-16 infrared image for 1831 EDT at 4X magnification with a standard MB temperature enhancement curve applied to highlight the higher and colder cloud tops typically associated with deep convection. The image depicted a large area of enhanced clouds immediately south of the turbulence location across central Georgia. The radiative cloud top temperature over the turbulence location was 264 Kelvin or -9.16°C , which corresponded to tops near 21,000 ft based on the HRRR sounding. The coldest cloud temperatures near -67°C (light blue area) were located over 50 miles south with cloud tops near 44,000 ft.

Figure 7 is the GOES-16 visible image for 1831 EDT at 4X magnification with the flight track and turbulence location noted. Two defined areas of towering cumulus congestus type clouds extend east and west of the flight track, with clouds over the turbulence location.



6.0 Weather Radar Imagery

The NWS Atlanta (KFFC) Weather Surveillance Radar 1988 Doppler (WSR-88D)²⁴ was located about 58 miles southwest of the turbulence location. The level II and III archive radar data were obtained from the NCEI using the Hierarchical Data Storage System and displayed using the NWS NEXRAD Interactive Viewer and Data Exporter software²⁵. The accident aircraft's flight track data was obtained and the ADS-B²⁶ data file and was then converted to a shape file and overlaid on the imagery. During the period, the KFFC WSR-88D was operating in the precipitation mode identified as volume scanning pattern 215 (VCP-215), where the radar makes 15 different elevation scans during an overall 6 minute scan. This scan is typically used in general precipitation situations and provides the most vertical resolution of any other scanning strategies.

Reflectivity is the measure of the efficiency of a target in intercepting and returning radio energy. With hydrometeors²⁷, it is a function of the drop size distribution, number of particles per unit volume, physical state (ice or water), shape, and aspect. Reflectivity is normally displayed in decibels (dBZ)²⁸ and is a general measure of echo intensity. The FAA Aviation Weather Handbook 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. For air traffic control purposes, the echo intensity terminology used to describe weather conditions to pilots as shown in the following table²⁹. Light rain is typically reported at the surface when reflectivities reach 20 dBZ, while air traffic control will not display information of echoes less than 30 dBZ or light intensity echoes on their weather displays or disseminate alerts of any such echoes.

²⁴ 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.

²⁵ <https://www.ncdc.noaa.gov/wct/>

²⁶ Automatic Dependent Surveillance-Broadcast (ADS-B) is a surveillance technology and form of Electronic Conspicuity in which an aircraft determines its position via satellite navigation or other sensors and periodically broadcasts it, enabling it to be tracked.

²⁷ Hydrometeors are any product of condensation or sublimation of atmospheric water vapor, whether formed in the free atmosphere or at 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.

²⁸ dBZ - Nondimensional "unit" of radar reflectivity which represents a logarithmic power ratio (in decibels, or dB) with respect to radar reflectivity factor, Z.

²⁹ FAA Aviation Weather Handbook - WSR-88D Radar Precipitation Intensity Terminology (Table 24-8).

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

6.1 Composite Reflectivity Imagery

The composite radar image depicts the highest reflectivity value from all the elevation scans for the period in dBZ, with a resolution at 1 x 1 km (0.54 x 0.54 nm) and provides a synopsis of the important features in the entire vertical coverage area. Figures 8-12 are the NWS KFFC WSR-88D composite reflectivity images from 1814 through 1841 EDT with the corresponding flight track overlaid (magenta) and to match the radar scan and the aircraft's flight patch during the period, and an aircraft symbol of DAL175 approximate position at the time. The images depict several areas of extreme intensity echoes of 55 dBZ and greater generally running west and east of ATL, with other echoes northeast of ATL developing as the accident flight descends into the area. Developing area of echoes of 30 to 35 dBZ are observed over the flight track at the time of the turbulence encounter, and further strengthen to 40 dBZ by 1841 EDT, with echoes of 50 dBZ on either side of the flight track and within 5 miles of the track. Figures 13-16 are the close-up depictions of the KFFC WSR-88D composite reflectivity for the same period between 1814-1841 EDT, with the corresponding flight track and DAL175 position during the period.

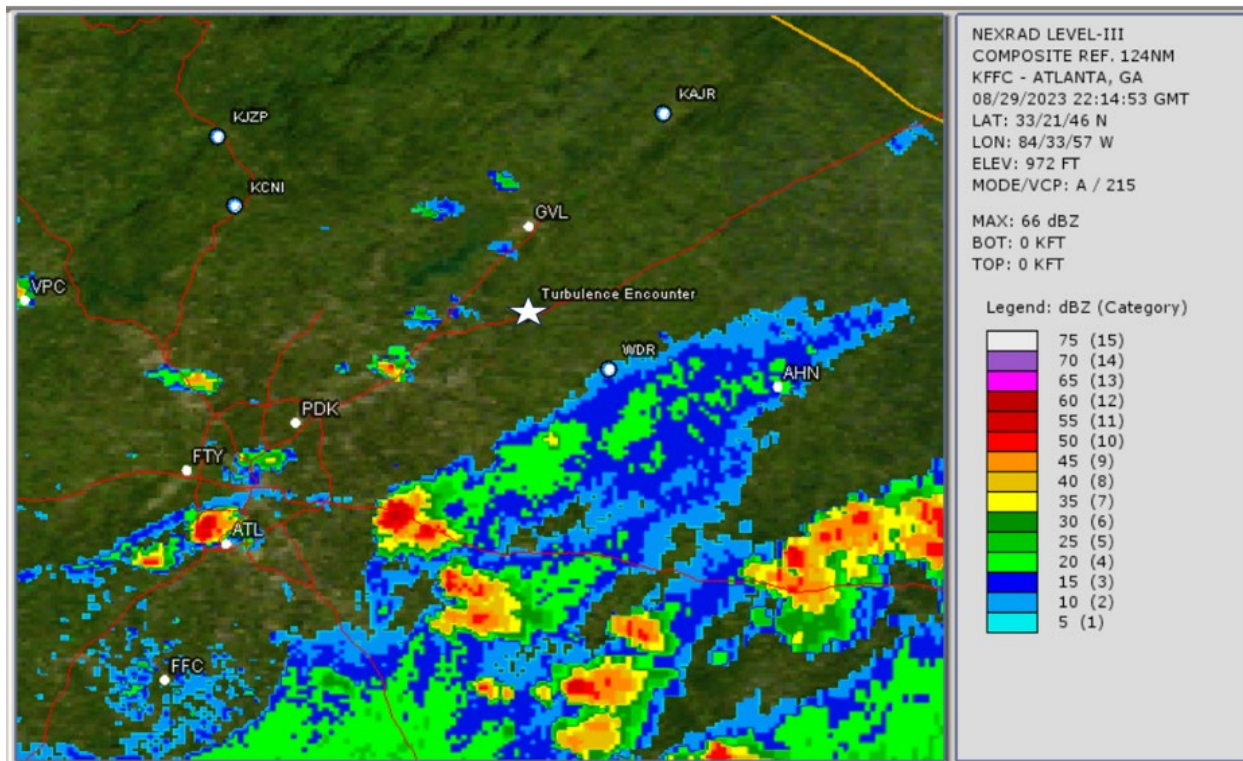


Figure 8 - NWS KFFC WSR-88D Composite Reflectivity image for 1814 EDT.

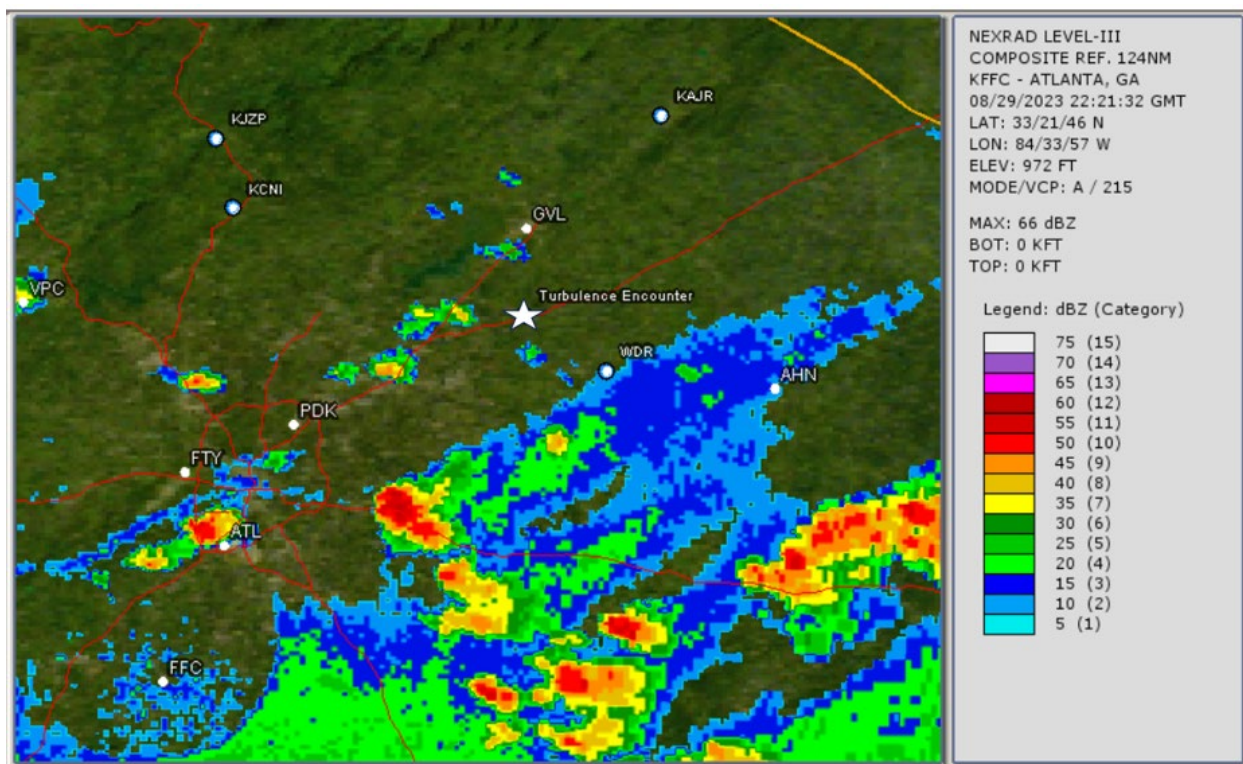


Figure 9 - NWS KFFC WSR-88D Composite reflectivity for 1821 EDT.

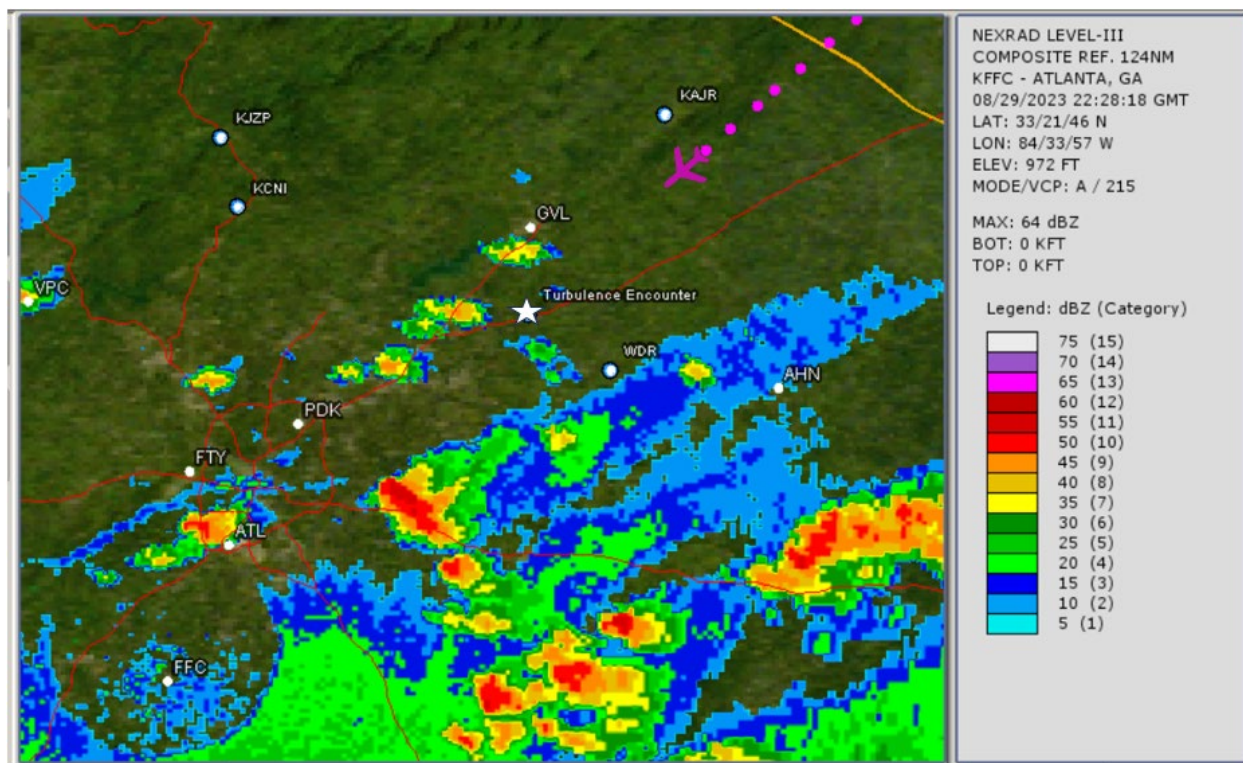


Figure 10 - NWS KFCC WSR-88D Composite Reflectivity for 1828 EDT with flight track.

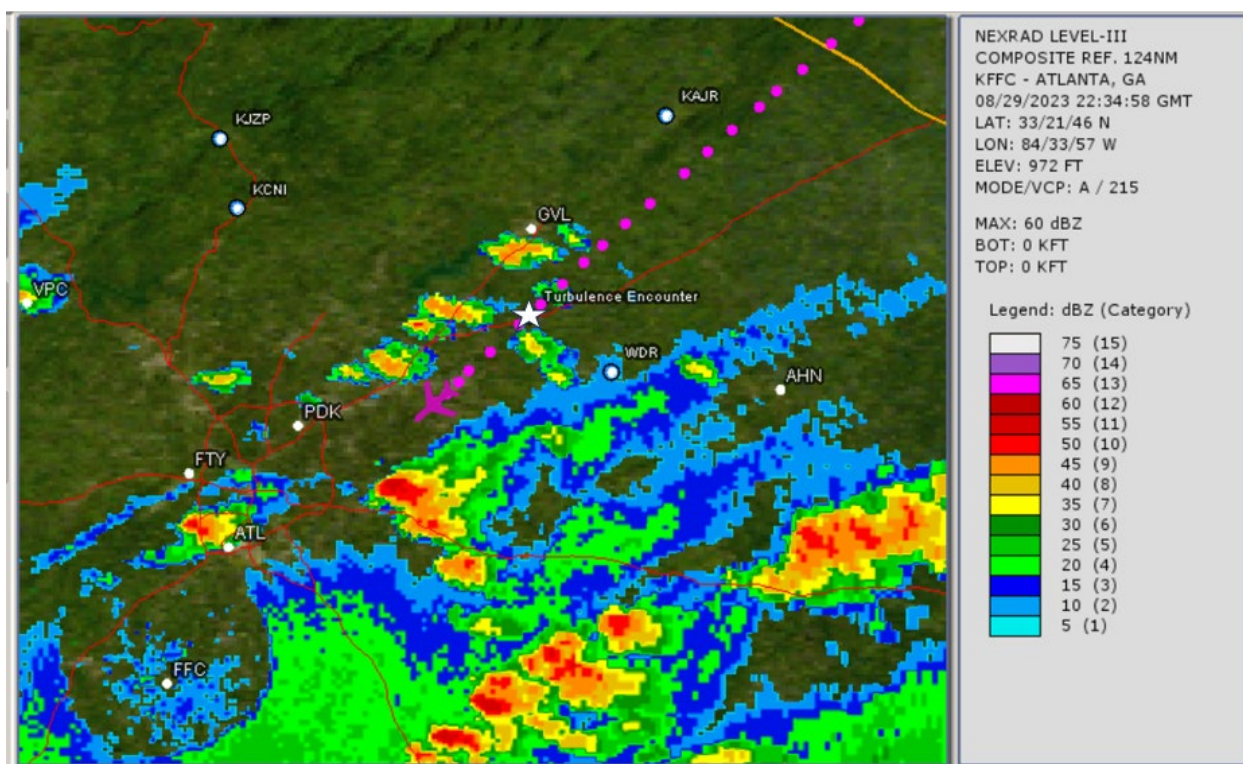


Figure 11 - NWS KFCC WSR-88D Composite Reflectivity for 1834 EDT with flight track overlaid.

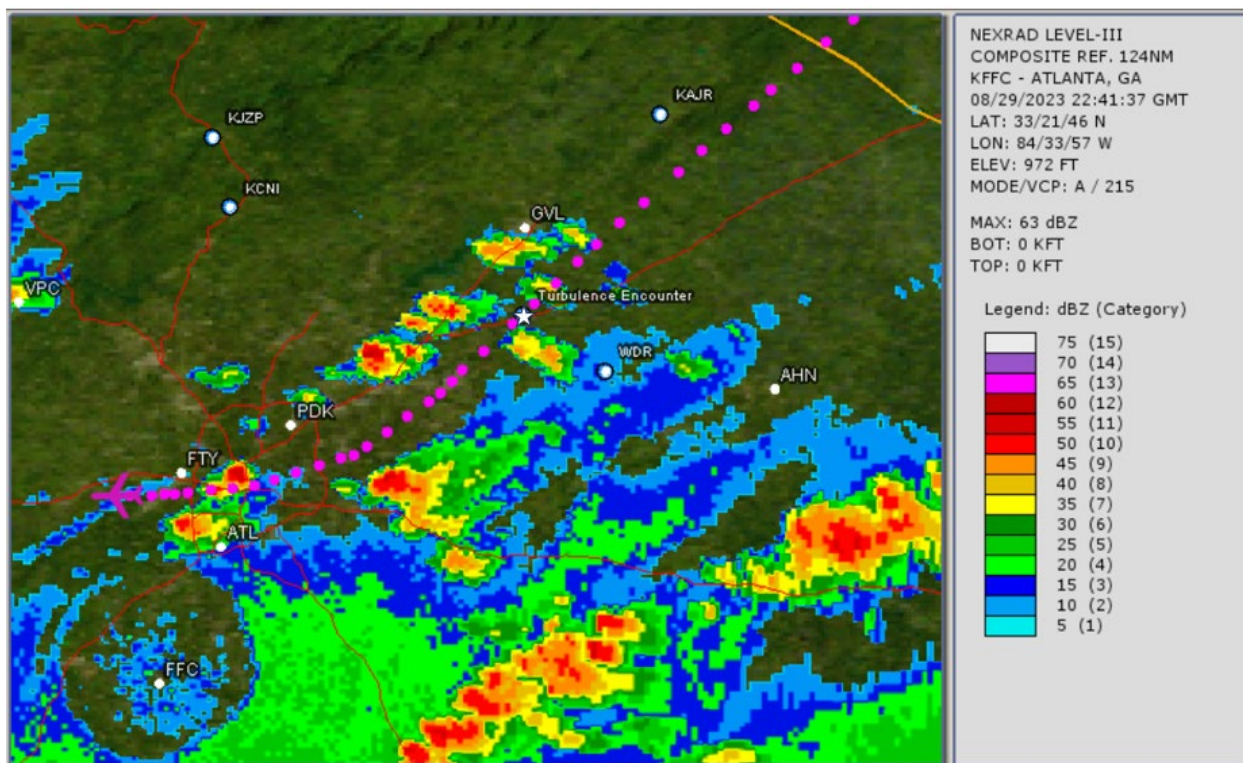


Figure 12 - NWS KFFC WSR-88D Composite Reflectivity for 1841 EDT with flight track overlaid.

ENLARGED VIEW OF COMPOSITE RADAR IMAGERY

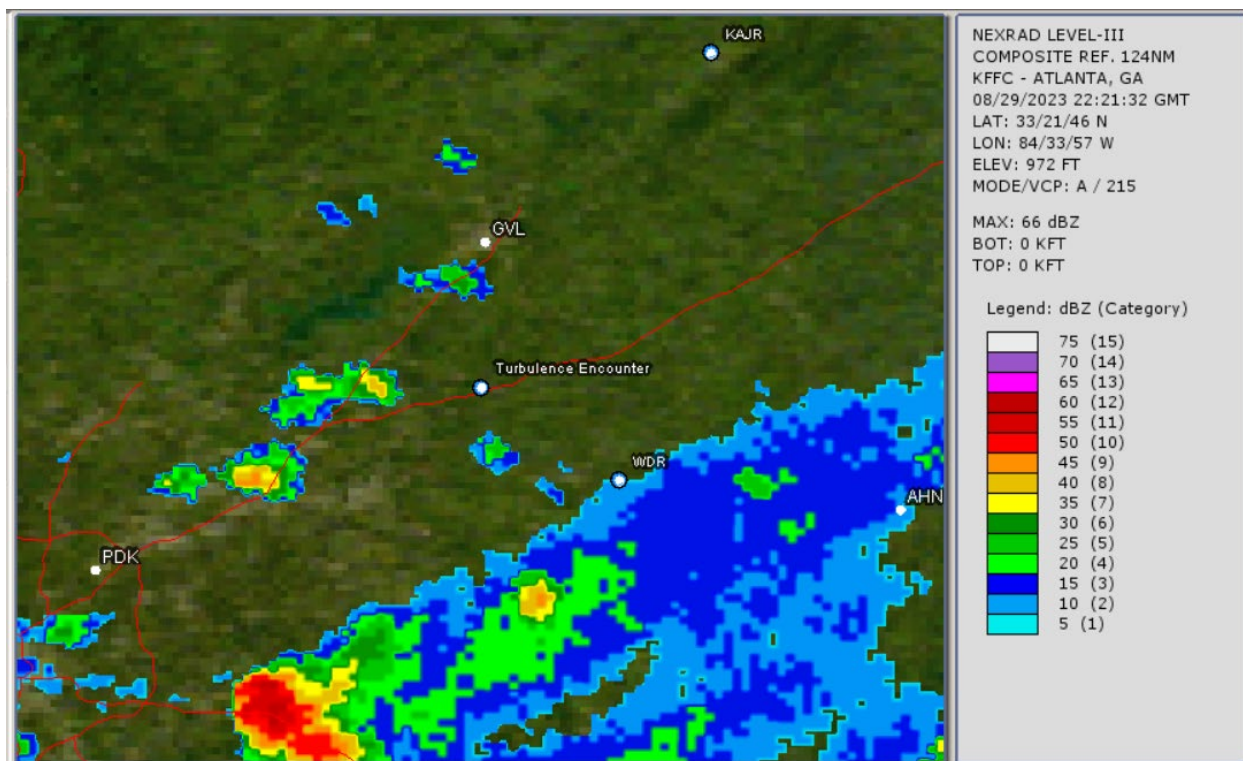


Figure 13 - Enlarged view of NWS KFFC WSR-88D Composite Reflectivity image for 1821 EDT.

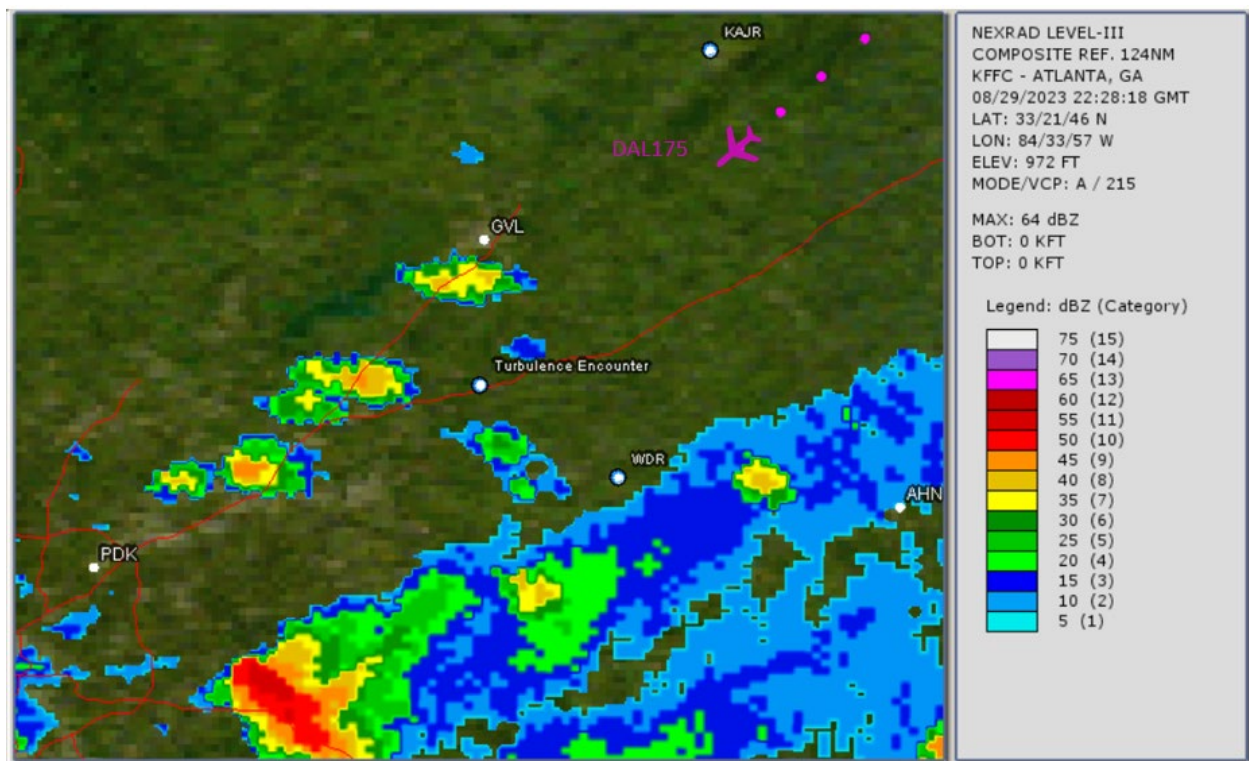


Figure 14 - Enlarged view of NWS KFCC WSR-88D Composite Reflectivity image for 1828 EDT.

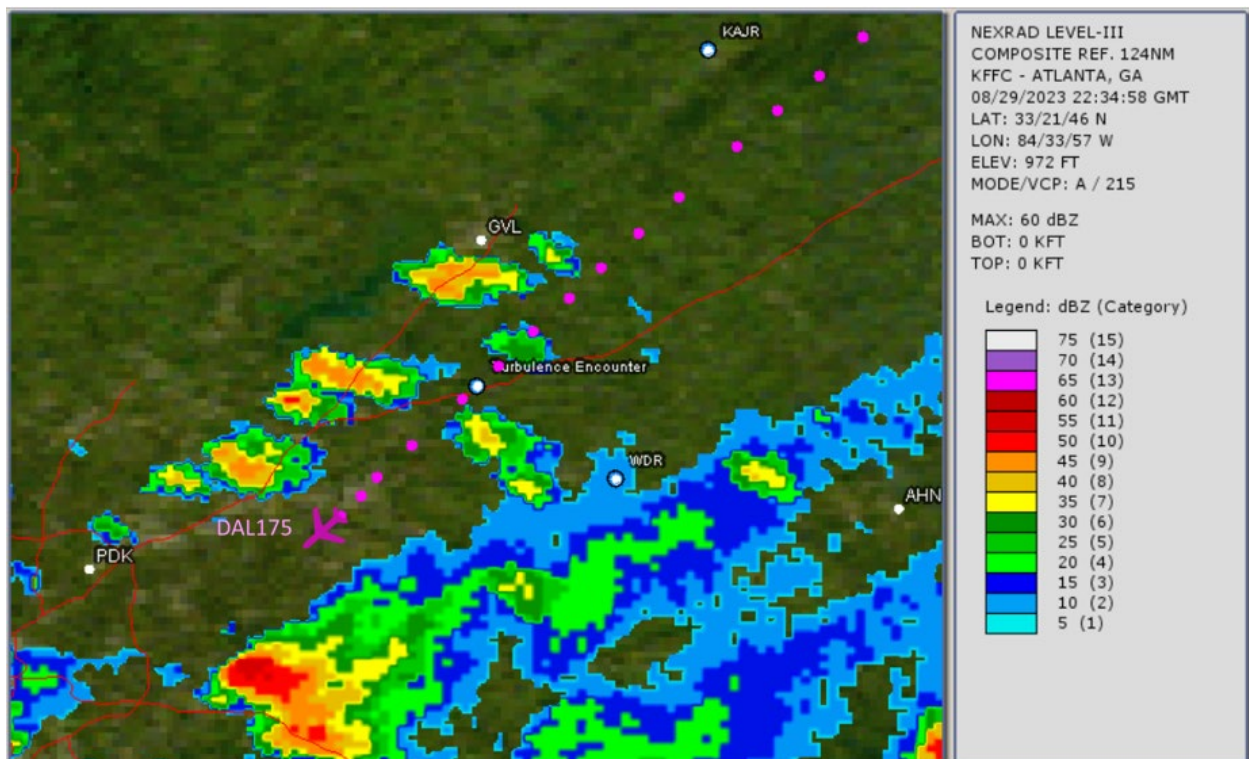


Figure 15 - Enlarged view of NWS KFCC WSR-88D Composite Reflectivity image for 1834 EDT.

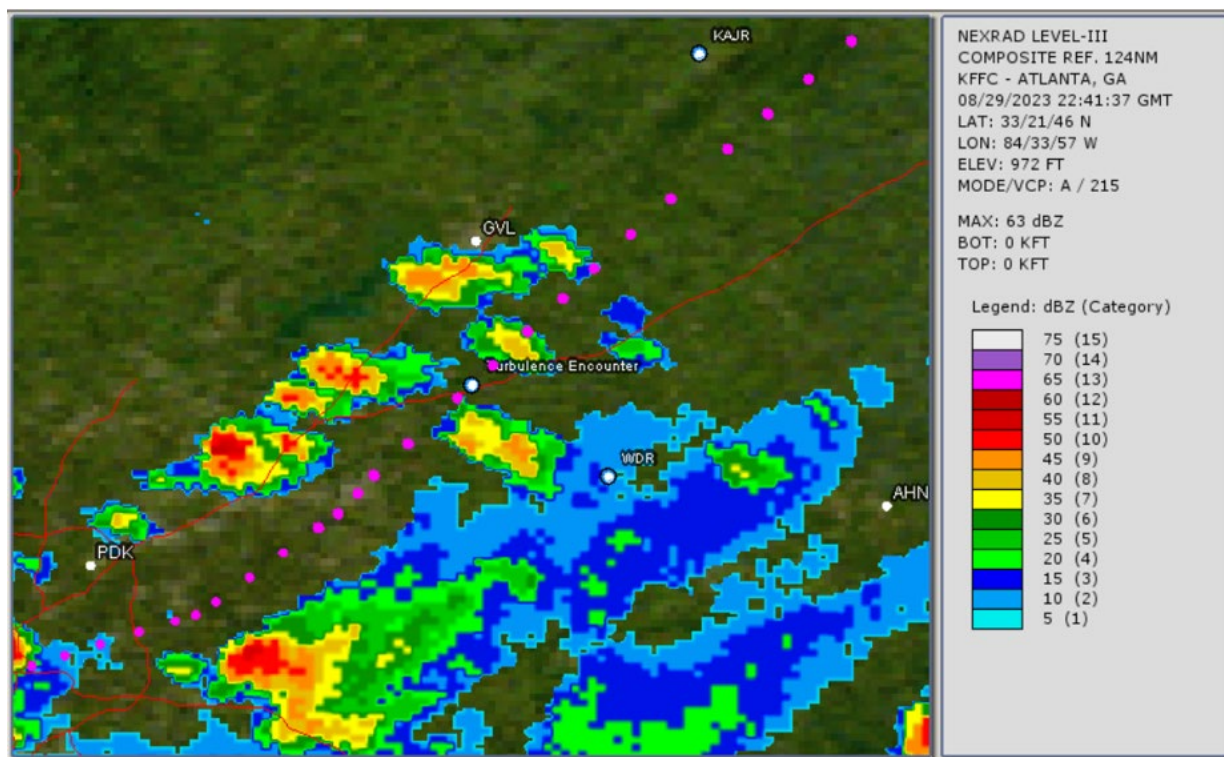


Figure 16 - Enlarged view of NWS KFFC WSR-88D Composite Reflectivity image for 1841 EDT.

6.2 Base Reflectivity Imagery

The WSR-88D base reflectivity image provides a higher resolution of 0.25 km (0.13 nm) X 0.5°. The KFFC WSR-88D 1.86° base reflectivity scan was sampling the layer between approximately 11,720 ft through 17,560 ft over the accident site, with the center of the beam at 14,640 ft assuming standard refraction of the radar beam. Figures 17-20 are the KFFC WSR-88D 1.86° base reflectivity images over the turbulence location from 1818 through 1841 EDT with the corresponding flight track (magenta) and DAL175 position by the aircraft symbol at the time. The images show an area of echoes developing at 1828 EDT at 10 to 20 dBZ and increases to 35 dBZ during the next sweeps at 1834 and 1841 EDT, and to 46 dBZ at 1848 EDT. Other echoes in the immediate vicinity also show rapid development with multiple cells exceeding 55 dBZ immediately after the turbulence event.

A search of Earth Networks lightning archive indicated that there were no lightning flashes detected within a 20 mile radius of the accident site between 1800 and 1845 EDT. Lightning was detected in the extreme intensity echoes immediate east of KATL or about 30 miles south-southwest of the turbulence location.

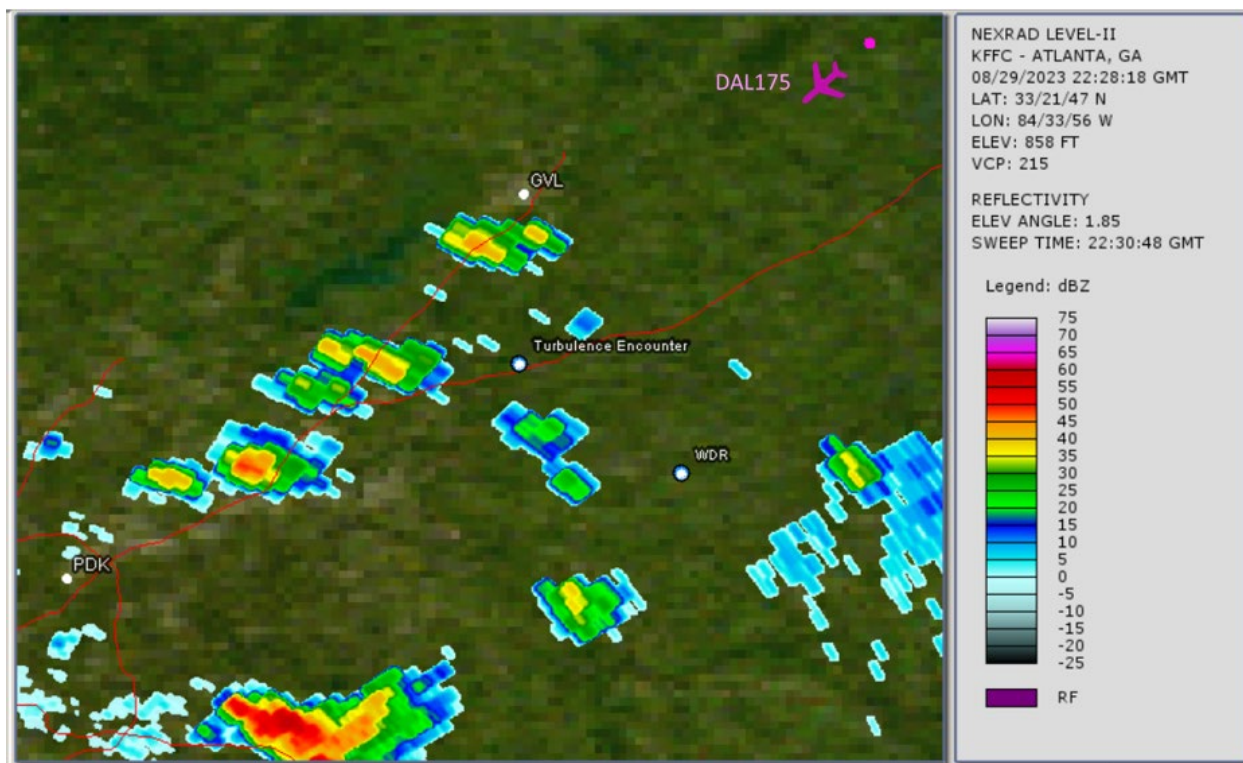


Figure 17 - NWS KFFC WSR-88D 1.86° base reflectivity image for 1828 EDT with track.

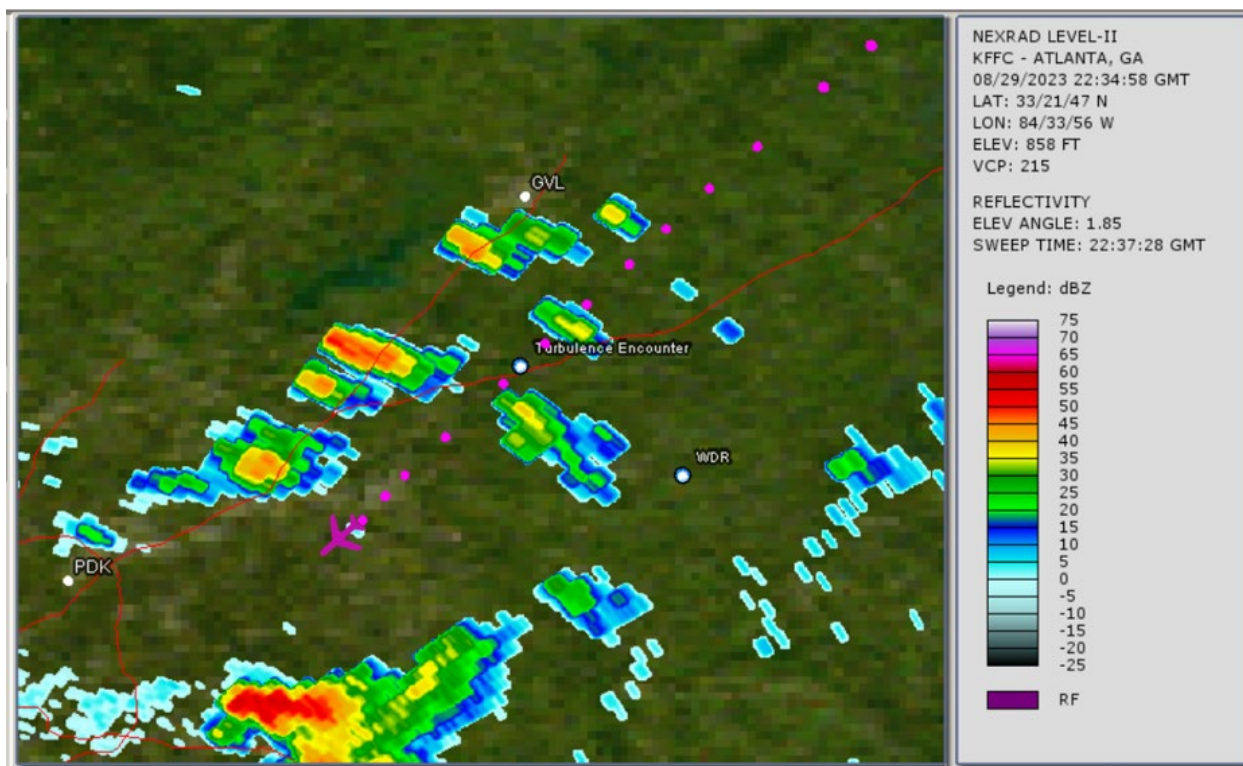


Figure 18 - NWS KFFC WSR-88D 1.86° base reflectivity image for 1834 EDT with track.

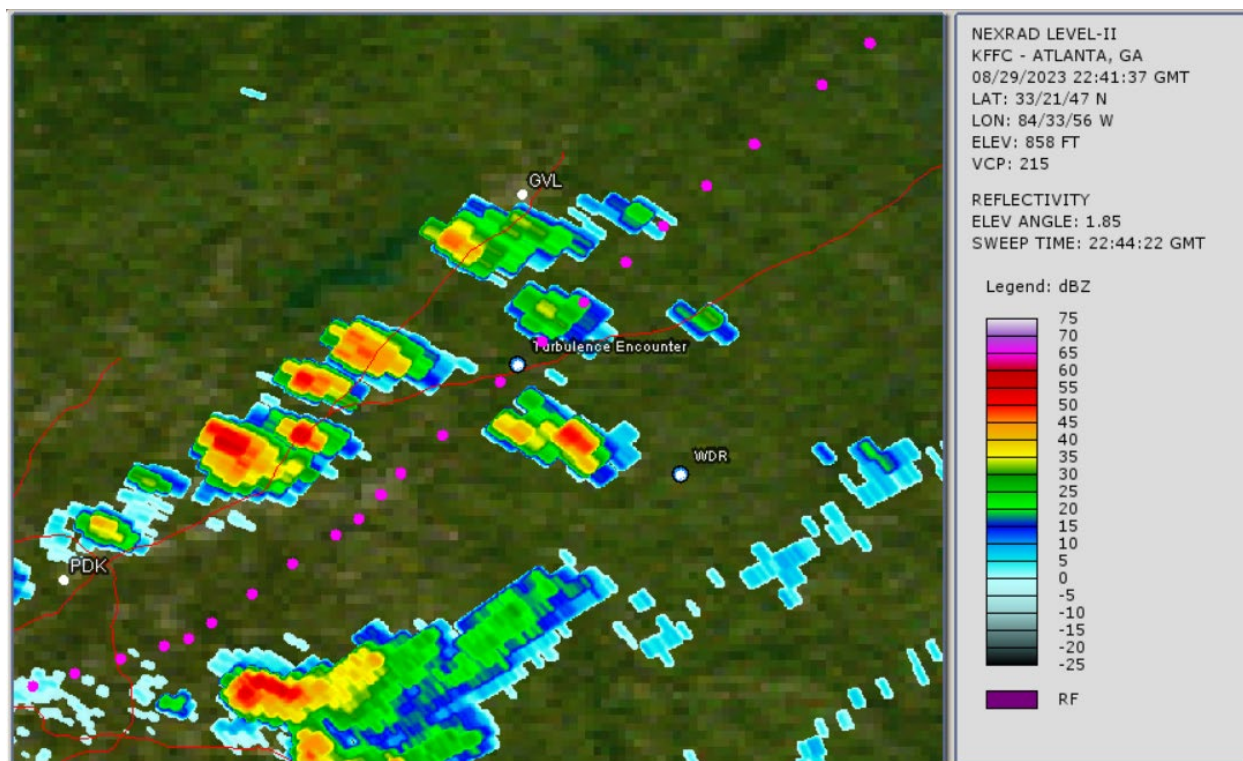


Figure 19 - NWS KFFC WSR-88D 1.86° base reflectivity image for 1841 EDT with track.

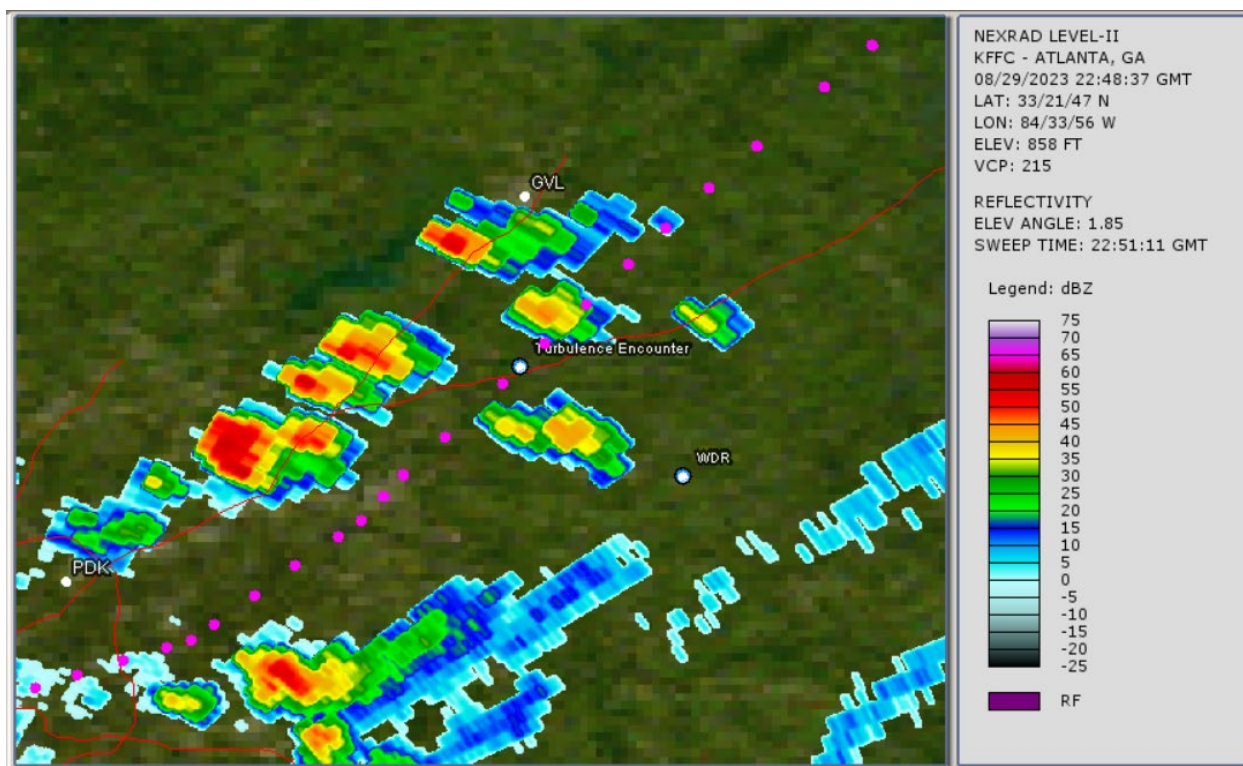


Figure 20 - NWS KFFC WSR-88D 1.86° base reflectivity image for 1848 EDT with track.

6.3 Radar Cross Section

A cross section of the NWS KFFC WSR-88D display from 1828 through 1848 EDT using the GR2 Analysis software³⁰ are included as figures 21-24 along the general flight path. At 1828 EDT an area of echoes of 10 to 20 dBZ begins to develop along the flight path with echoes to about 8,000 ft (figure 21). By 1834 EDT the aircraft has flown over the echo which has increased to 30 dBZ and reached 19,000 ft (figure 22). By 1841 EDT immediately after the event, echoes reached 45 dBZ below 10,000 ft with echo tops to 22,000 ft (figure 23). The last image at 1848 EDT (figure 24) the area of echoes of 45 dBZ expands through 10,000 ft with tops near 22,000 ft.

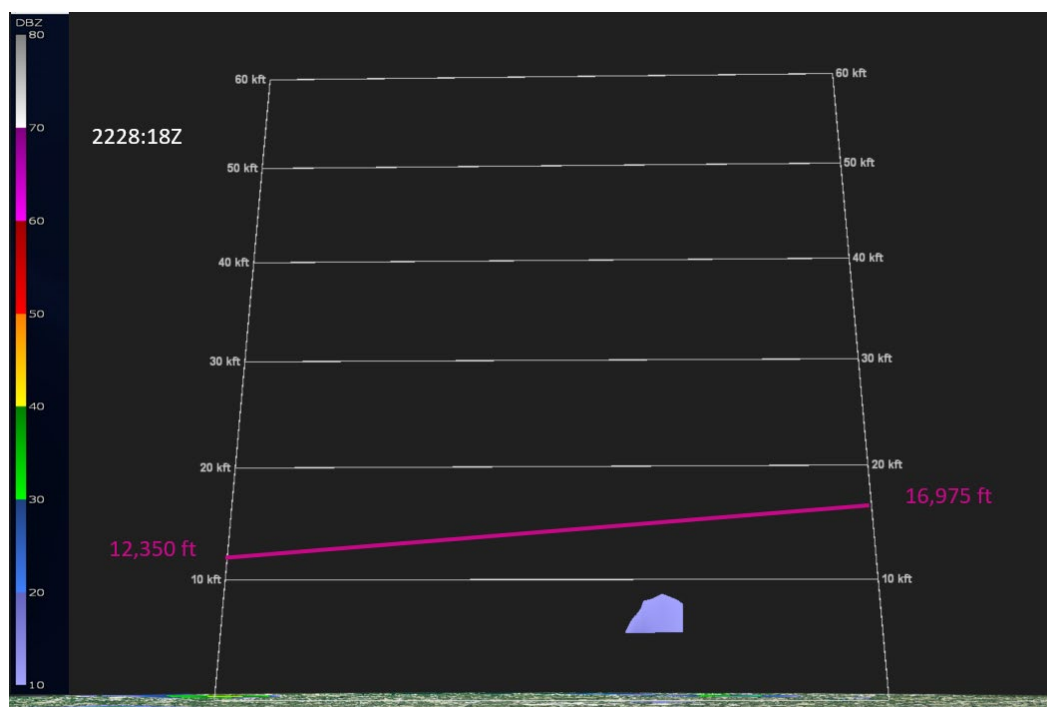


Figure 21 - NWS KFFC WSR-88D cross section for 1828 EDT along flight path.

³⁰ GR2Analyst Version 2 is a Nexrad Level II analysis application. http://www.grlevelx.com/gr2analyst_2/

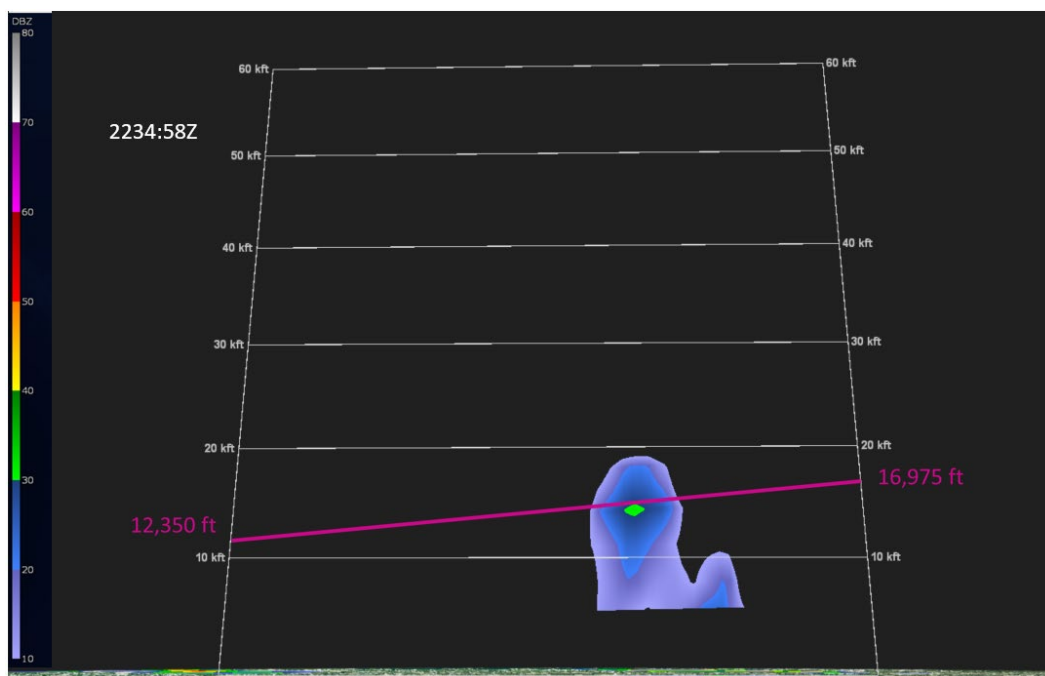


Figure 22 - NWS KFFC WSR-88D cross section for 1834 EDT along flight path.

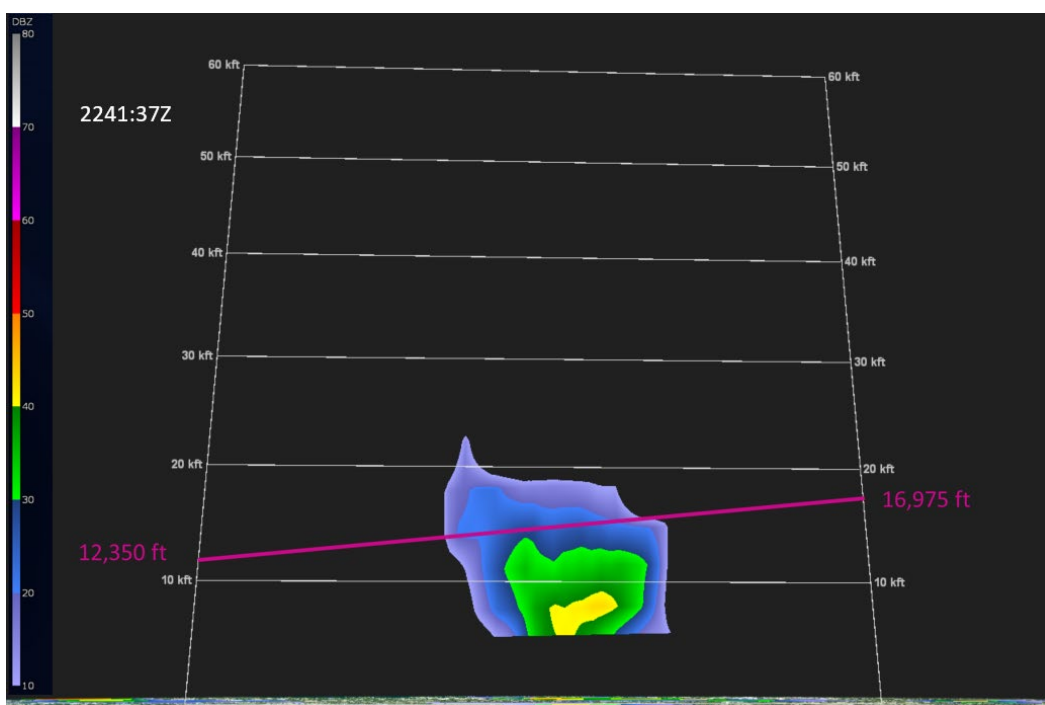


Figure 23 - NWS KFFC WSR-88D cross section for 1841 EDT along flight path.

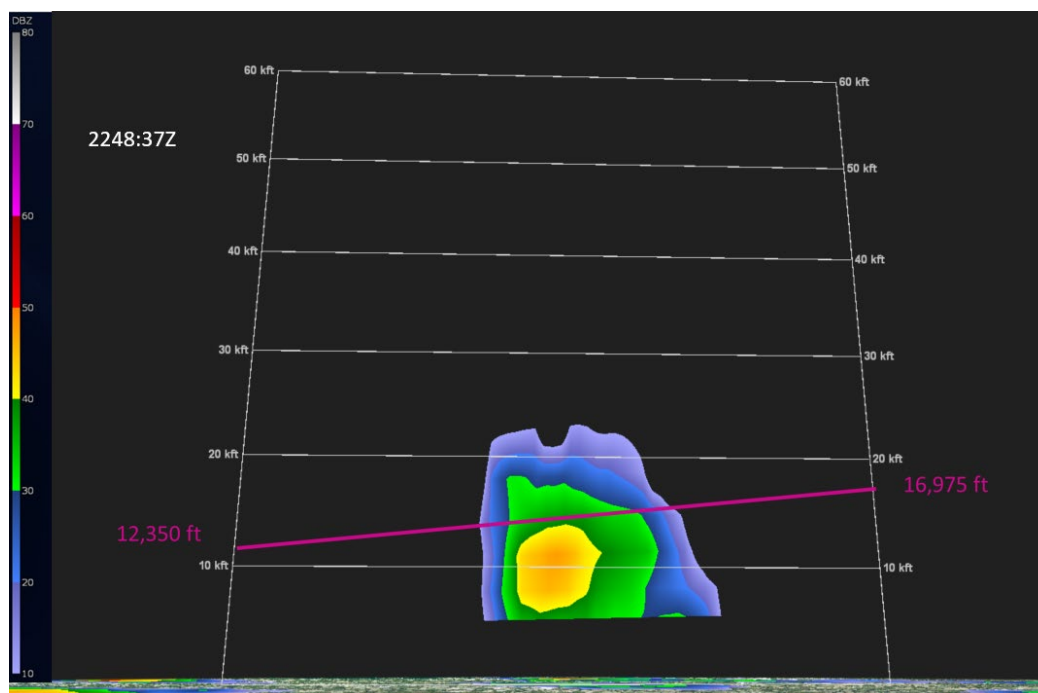


Figure 24 - NWS KFFC WSR-88D cross section for 1848 EDT along flight path.

6.4 FAA Consolidated Storm Prediction for Aviation Display

The Massachusetts Institute of Technology (MIT) Lincoln Laboratory developed Consolidated Storm Prediction for Aviation (CoSPA) developed for the FAA and is presently used in the Atlanta Air Route Traffic Control Centers (ARTCC) to provide improved situational awareness of weather radar and lightning data. The imagery provides a depiction of vertical integrated liquid (VIL) precipitation levels versus echoes in dBZ, which is included in figure 25. The product also provides echo tops, cell movement, and lightning data. The program also provides an algorithm growth and decay feature.

VIP or VIL Levels	VIL (digital VIL)	VIL (kg/m ²)	Past and Current VIL	Forecast VIL
1	16	0.15	Level 1	Level 1
2	74	0.76	Level 2	Level 2
3	133	3.47	Level 3	Level 3/4
4	160	6.92	Level 4	Level 3/4
5	181	12.0	Level 5	Level 5/6
6	219	31.6	Level 6	Level 5/6

Figure 25 - VIL Precipitation Levels.

Figures 26-30 are the CoSPA images for 1825, 1830, 1835, 1840, and 1845 EDT over the Atlanta area. The images depicted no significant echoes over the general flight path where the turbulence occurs until 1840 EDT (figure 29), when echo tops reaching 25,000 ft immediately after the event. The growth and decay product (not shown) indicated almost all the areas of echoes west of turbulence location and KATL were expected to increase in intensity and area coverage or growth.

The CoSPA imagery indicated that there were no lightning flashes detected within a 20 mile radius of the accident site between 1800 and 1845 EDT. While cloud-to-ground lightning were detected beyond 30 miles south of the turbulence location and east of KATL indicated by the "+" symbol on the CoSPA imagery.

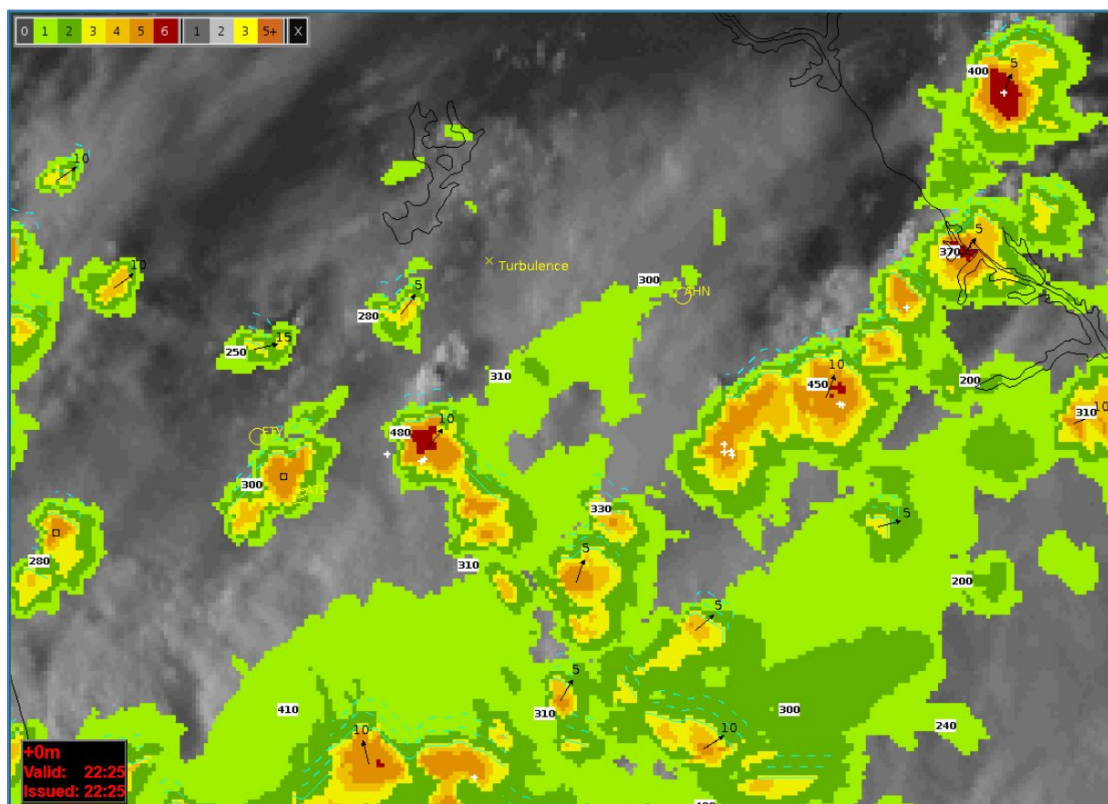


Figure 26 - Consolidated Storm Prediction for Aviation VIL image for 1825 EDT.

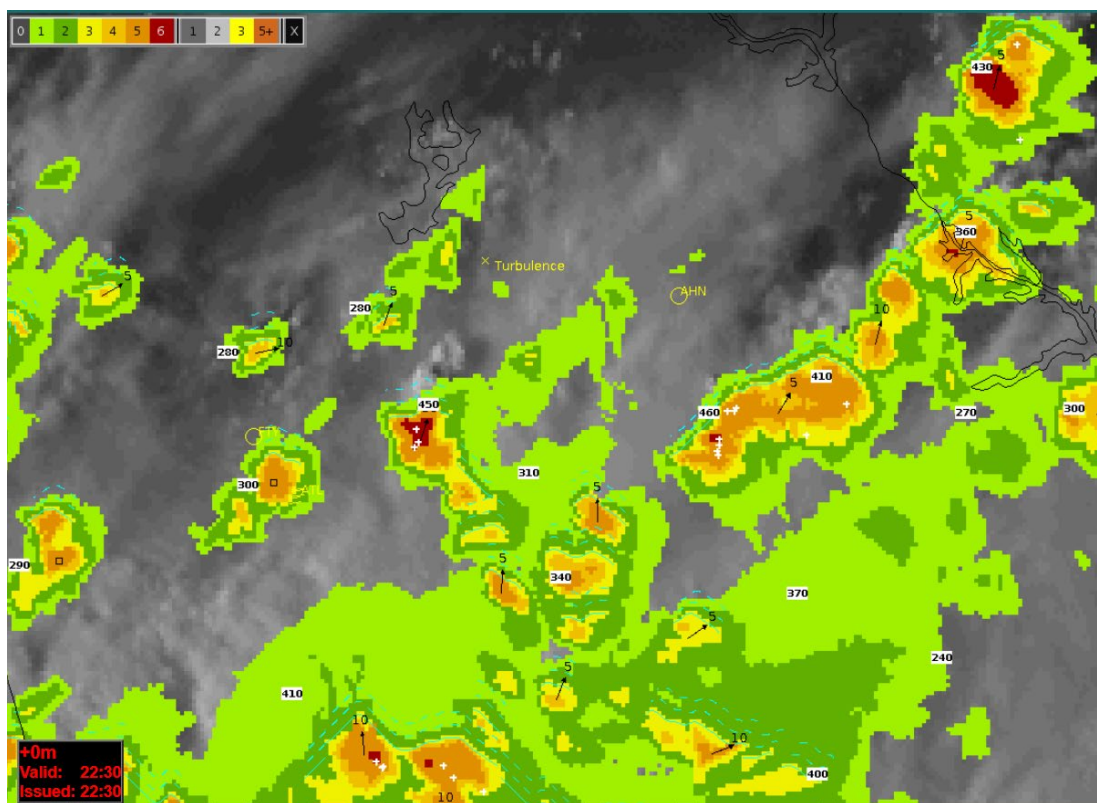


Figure 27 - Consolidated Storm Prediction for Aviation VIL image for 1830 EDT.

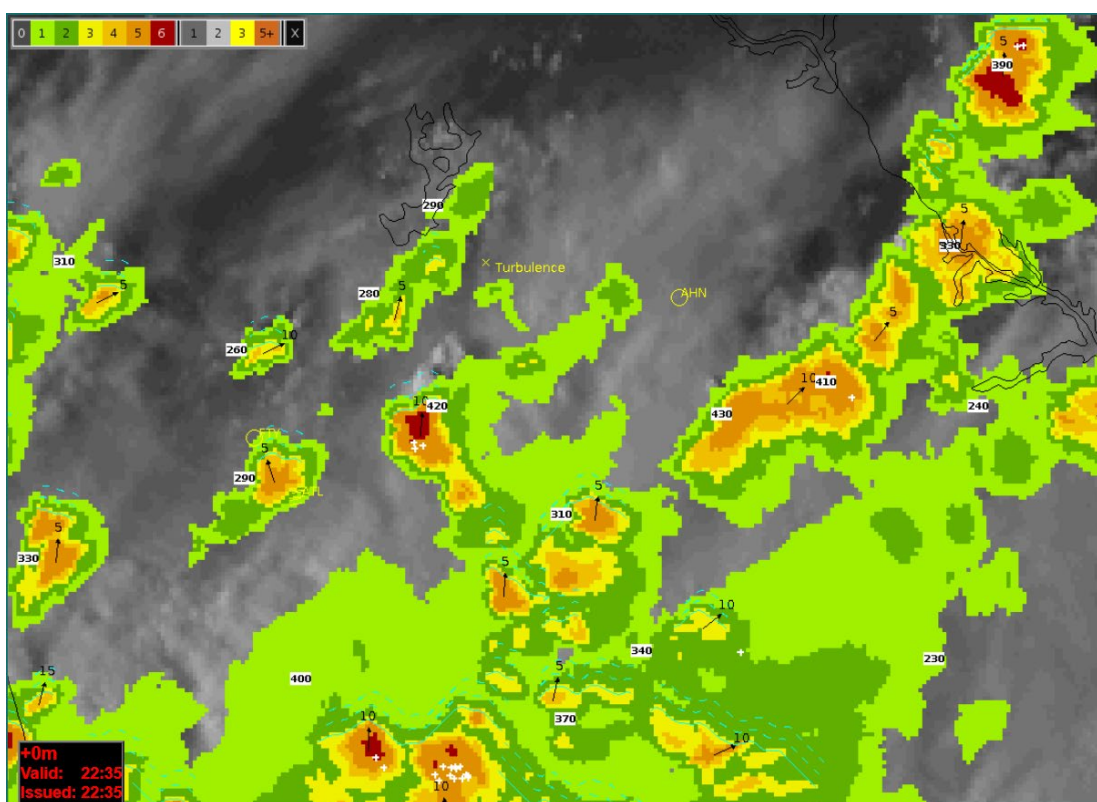


Figure 28 - Consolidated Storm Prediction for Aviation VIL image for 1835 EDT.

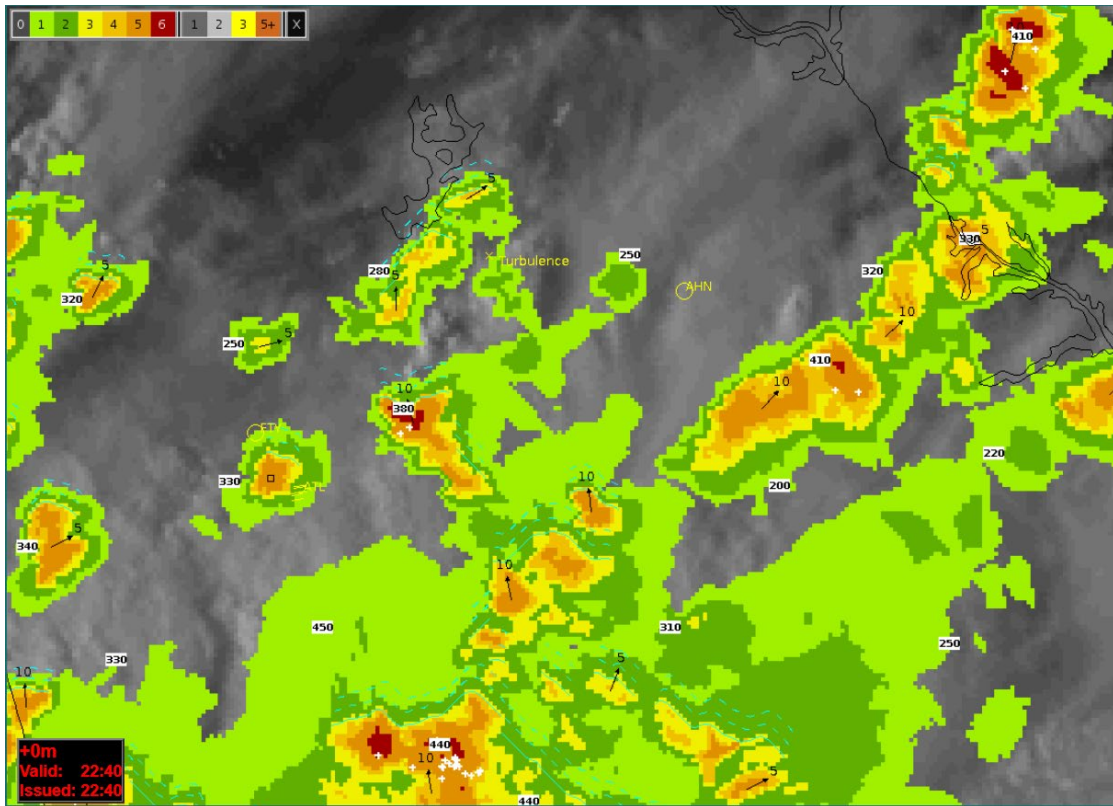


Figure 29 - Consolidated Storm Prediction for Aviation VIL image for 1840 EDT.

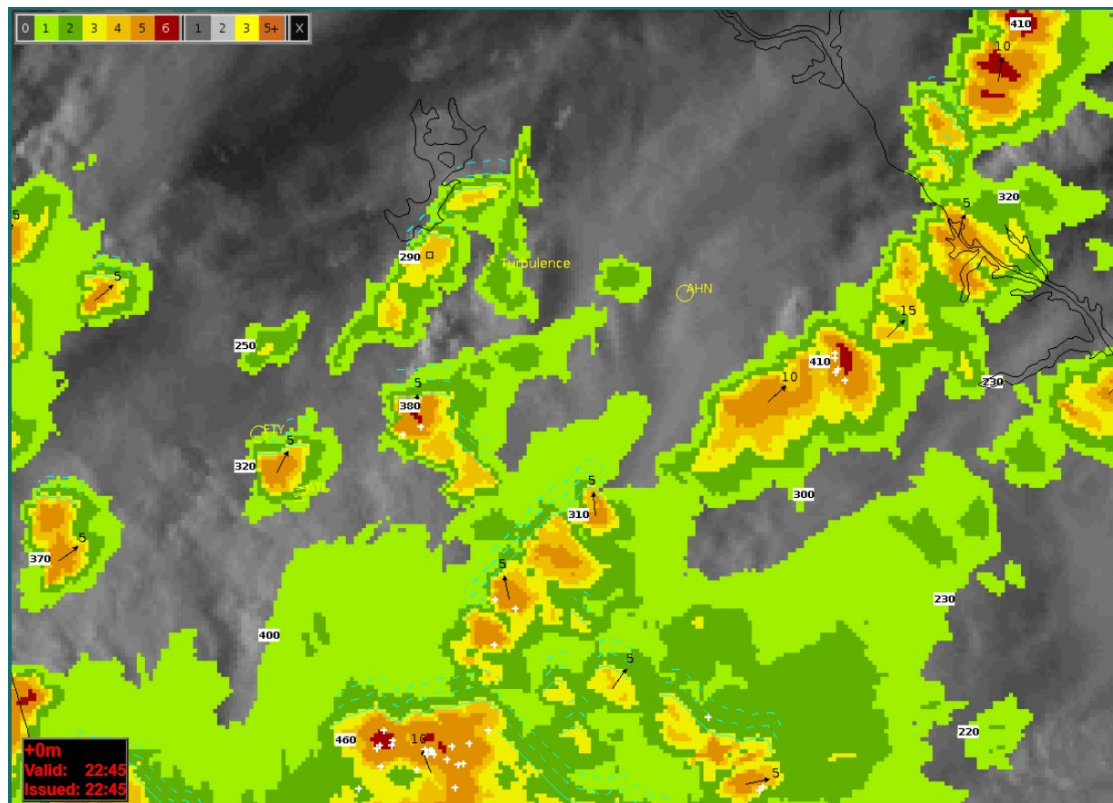


Figure 30 - Consolidated Storm Prediction for Aviation VIL image for 1845 EDT.

7.0 NWS Forecasts

7.1 Convective Outlook

The NWS Storm Prediction Center (SPC) located in Norman, Oklahoma, is tasked to identify and provide timely warnings and watches for severe thunderstorms, which may produce tornadoes, large hail of an inch or greater in diameter, or thunderstorms with organized wind gusts of 50 knot or more across the continental United States. One of the products they produce and is used in aviation is the Convective Outlook graphic and bulletin (AC) which identifies where organized thunderstorms are expected during the period of the outlook, typically 24-hours. Figure 31 is the afternoon Convective Outlook issued at 1451 EDT and valid until 0800 EDT on August 30, 2023. The chart depicted a marginal³¹ and slight risk³² of severe storms over Florida and extreme southern Georgia. The chart depicted only a general risk of airmass non severe thunderstorms over the rest of Georgia and most of the east coast.

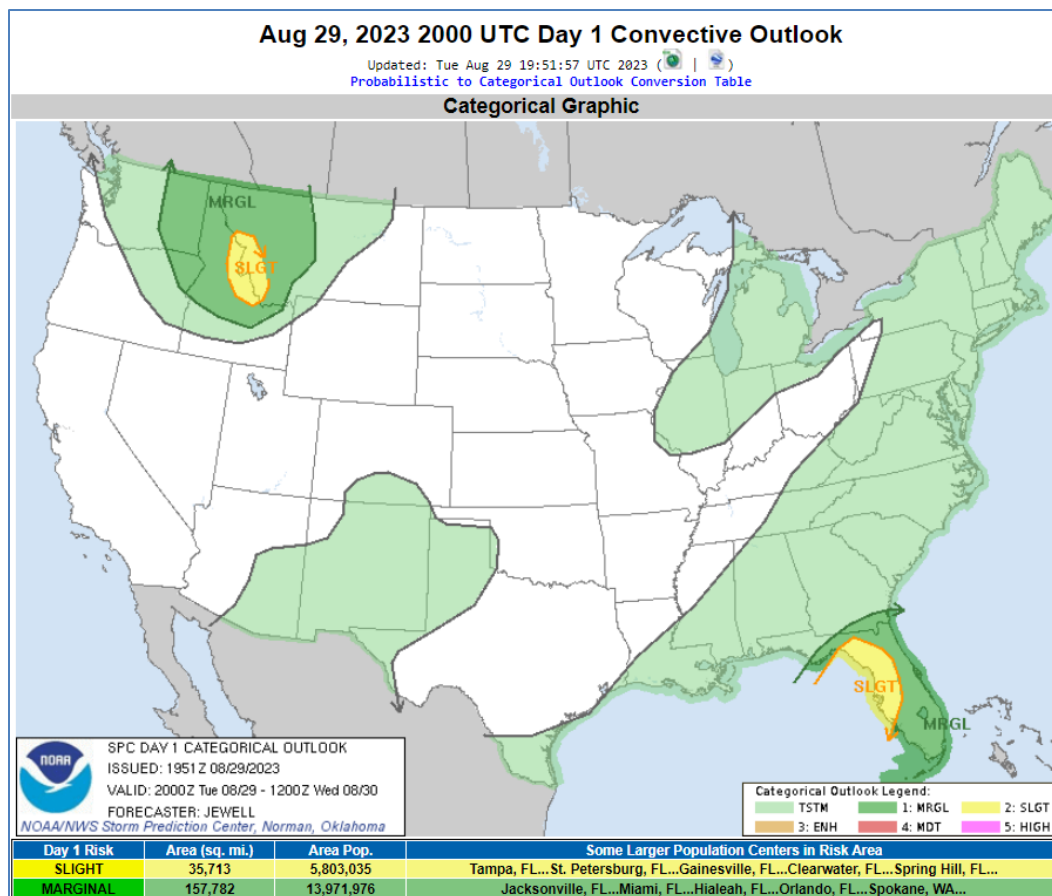


Figure 31 - NWS Storm Prediction Center's Convective Outlook issued at 1551 EDT.

³¹ Marginal risk - An area of severe storms of either limited organization and longevity, or very low coverage and marginal intensity. About 2% probability of occurrence.

³² Slight risk - An area of organized severe storms, which is not widespread in coverage with varying levels of intensity. About a 5% probability of occurrence.

The text bulletin issued in association with the graph was as follows.

SPC AC 291951

Day 1 Convective Outlook
NWS Storm Prediction Center Norman OK
0251 PM CDT Tue Aug 29 2023

Valid 292000Z - 301200Z

...THERE IS A SLIGHT RISK OF SEVERE THUNDERSTORMS OVER PARTS OF FLORIDA IN ASSOCIATION WITH HURRICANE IDALIA...AND CENTERED OVER THE BITTERROOTS...

...SUMMARY...

A few tornadoes will be possible late this afternoon through tonight, mainly from the west central Florida Peninsula into the Big Bend area, within the northeast quadrant of strengthening Hurricane Idalia. Occasional damaging wind gusts will be possible across the northern Rockies.

...20Z Update...

Little change was made to the existing severe probabilities at 20Z, except for a minor eastward shift for a low wind threat into central MT where minimal instability will develop due to steepening lapse rates.

For the Southeast, the threat for a few tornadoes will increase tonight, primarily after 03Z as stronger shear associated with Hurricane Idalia overspreads parts of the western FL Peninsula, and eventually into parts of the Big Bend.

..Jewell.. 08/29/2023

.PREV DISCUSSION... /ISSUED 1128 AM CDT Tue Aug 29 2023/

...FL Gulf coast through tonight...

Hurricane Idalia is strengthening as of midday over the southeast Gulf of Mexico and is forecast to make landfall Wednesday morning near the FL Big Bend as a major hurricane (please see latest NHC advisories for additional information). Storm motion will be largely parallel to the FL west coast into early tonight, so eastward expansion of the stronger wind field and more favorable low-level hodograph structures will be a gradual process (per the trends in the VWP's from Key West and Tampa). Surface observations show 77-80 F dewpoints across almost all of central/south FL, which will help maintain surface-based buoyancy into this evening and overnight. Thus, the primary increase in supercell/tornado threat is expected late this afternoon into tonight from near Tampa northward along the coast with the more cellular convection within the outer eastern/northeastern bands.

...Northern Rockies this afternoon/evening...

A midlevel shortwave trough now over far northern CA and OR will progress east-northeastward toward the northern Rockies by this evening. Though low-level moisture is rather limited, strong surface heating/deep mixing will result in inverted-V profiles with weak buoyancy in advance of the midlevel trough and an associated cold front. Thunderstorm development is expected this afternoon through early tonight in the zone of ascent preceding the midlevel trough (and along the front). The highest confidence in storm development coincident with the steep low-level

lapse rates and some enhancement to midlevel flow will be later this afternoon over the Bitterroots, where a few damaging outflow gusts of 60-70 mph will be possible.

NOTE: THE NEXT DAY 1 OUTLOOK IS SCHEDULED BY 0100Z

The main concern for thunderstorms with potential tornadoes was over Florida as Hurricane Idalia moved towards the northwest Gulf coast. The second area of concern was over Idaho and western Montana in the northern Rockies or Bitterroot Mountains. There was no mention of storms over Georgia during the period.

7.2 Terminal Aerodrome Forecast

The Terminal Aerodrome Forecast (TAF) is a concise statement of the expected meteorological conditions significant to aviation for a specified time period (usually 24- or 30-hours) and within 5 statute miles of the center of the airport's runway complex (terminal). The forecasts issued for KATL during the period from the NWS Peachtree City, Weather Forecast Office (WFO) were as follows.

TAF KATL 291753Z 2918/3024 12007KT P6SM VCSH SCT025 BKN100

TEMPO 2922/3002 VRB15G25KT 3SM TSRA BKN025CB

FM300400 10004KT P6SM VCSH BKN025

FM300800 08006KT 6SM BR SCT004 OVC006

FM301600 06010KT P6SM VCSH BKN015=

AMD TAF KATL 292003Z 2920/3024 13007KT P6SM VCSH SCT025 BKN100

TEMPO 2921/3001 VRB15G25KT 3SM TSRA BKN025CB

FM300400 10004KT P6SM VCSH BKN025

FM300800 08006KT 6SM BR SCT004 OVC006

FM301600 06010KT P6SM VCSH BKN015=

AMD TAF KATL 292145Z 2922/3024 13007KT P6SM VCSH SCT025 BKN100

TEMPO 2922/3001 VRB15G25KT 3SM TSRA BKN025CB

FM300400 10004KT P6SM VCSH BKN025

FM300800 08006KT 6SM BR SCT004 OVC006

FM301600 06010KT P6SM VCSH BKN015=

The forecast for KATL issued at 1745 EDT expected a wind from 130° at 7 knots, visibility 6 miles or more, with rain showers in the vicinity³³ of the airport, scattered clouds at 2,500 ft agl, ceiling broken at 10,000 ft, with a temporary period between 1800 and 2100 EDT of winds variable at 15 knots gusting to 25 knots, visibility 3 miles in thunderstorm and moderate rain, ceiling broken at 2,500 ft in cumulonimbus clouds.

Delta Air Lines has a Meteorology Department and in their Operation Specifications A10 is an FAA approved Enhanced Weather Information System (EWINS) provider. This allows Delta to issue their own terminal forecasts and adverse

³³ Vicinity is defined as between 5 and 10 statute miles from the station.

weather advisories to control their flights. Those products were not evaluated in this report. Attachment 1 is the Delta Air Lines provided preliminary review of the weather conditions related to the turbulence encounter.

7.3 Area Forecast Discussion

The NWS Area Forecast Discussions (AFD) are issued by each WFO to describe the short-term weather conditions within their region with an aviation section that includes the general conditions as they relate to the creation of the TAF. These are useful for additional aviation-related issues that cannot be encoded into the TAF and provide some reasoning behind the forecast. These are generated roughly every 6 hours and correspond to the release of the latest TAFs for that office. The NWS Atlanta/Peachtree City WFO 1610 EDT discussion was as follows.

*FXUS62 KFFC 292010
AFDFFC*

*Area Forecast Discussion
National Weather Service Peachtree City GA
410 PM EDT Tue Aug 29 2023*

...New Update for Expanded Flood Watch...

*.UPDATE...
Issued at 409 PM EDT Tue Aug 29 2023*

Have expanded the Flood Watch another row of counties north and west of the previous watch area to account for a slightly more west axis of heaviest rainfall. No other changes at this time, although updates will be ongoing through the afternoon.

*.SHORT TERM...
(This afternoon through Wednesday)
Issued at 248 PM EDT Tue Aug 29 2023*

Main Forecast Points:

-Scattered to widespread storms expected through the evening today (potentially lingering overnight) with locally heavy rainfall and isolated damaging wind gusts with any storms that form this afternoon.

-'Cooling' trend continues as a result of rain chances and cloud cover.

-Slight westward shift in the track of Hurricane Idalia.

Currently...Scattered thunderstorms are ongoing this afternoon across portions of south-central GA. The stationary boundary that was bisecting the forecast area has since lifted back northward. Storms are expected to persist through the evening though may linger into the overnight hours. With no changes to the juicy environment, locally heavy rainfall and damaging wind gusts will be the primary hazards with any storms that develop today

(similar to yesterday). SBCAPE values are 3000-4000 J/kg, DCAPE values are 700-900 J/kg and PWATs are well over 2"...so certainly plenty of fuel for storms to work with. Coverage of showers and storms may be slightly less overnight but more rain will be on the way as we start to feel the impacts from the outer rainbands of Hurricane Idalia overnight.

Latest NHC Advisory has Hurricane Idalia making landfall along the coastline of "Big Bend" area of Florida around sunrise Wednesday morning. As this occurs, outer banding will begin to approach portions of Middle Georgia overnight tonight and early tomorrow (Wednesday) morning. Per this latest advisory, there was a slight westward shift in the track of Hurricane Idalia thus impacts from winds and heavy rain have been expanded further north and west into the forecast area, encompassing more of east- central Georgia. After making landfall, Idalia will steadily move into southeast Georgia by the afternoon and evening hours on Wednesday. With the track of Hurricane Idalia trending slightly more westward, elected to expand the Flood Watch (again) another tier of counties north and westward. The HREF LPMM (ensemble probability mean) was also a player in this decision and has done well with the predictability in QPF totals. Forecast storm total rainfall has also increased to now be 4 to 8 inches across southeast Georgia with pockets of rainfall up to 10" possible.

Sustained winds across portions of southeast Georgia are forecast to range from 20-30 mph with gusts as high as 45 mph from late Wednesday morning through Wednesday night. A Tropical Storm Warning is now in effect for Toombs, Montgomery, Wheeler, Telfair, Dodge, Wilcox, and Crisp counties. In addition, a Tropical Storm Watch has been issued to the north for Emanuel, Treutlen, Laurens, Johnson, Bleckley, Pulaski, and Dooly counties. A tornado threat will also exist within the rainbands as Idalia moves onshore and approaches our area. As we have seen over the past 24-48 hrs, any adjustment of the track further to the west may increase potential impacts for portions of Middle Georgia. Changes may be forthcoming following the next NHC Advisory.

Thanks to cloud cover and rainfall temperatures tomorrow will be noticeably cooler...yay. Highs forecast to be in the 70s to low 80s. Low temperatures forecast to be in the 60s.

.AVIATION...

(18Z TAFS)

Issued at 201 PM EDT Tue Aug 29 2023

Cigs have been a little slower to scatter out today with a mixed bag of MVFR to low VFR. Lower VFR cigs expected through the afternoon with MVFR cigs associated with any storms that develop. **Scattered -shra/-tsra has already begun to develop and activity will likely persist until 05-06z.** TEMPOs may need to be extended. Low cigs, likely IFR, expected again overnight beginning around 06-07z Wednesday. Winds are expected to remain on the east side through the period though this afternoon taking a slightly more SE component.

//ATL Confidence... 18Z Update...

Medium confidence on cigs overnight and shra/tsra timing. High confidence all other elements.

.PRELIMINARY POINT TEMPS/POPS...

Athens	70	77	67	81	/	70	90	50	30
Atlanta	72	79	66	85	/	70	90	30	20
Blairsville	64	78	59	80	/	50	70	30	30
Cartersville	69	82	63	84	/	60	70	30	20
Columbus	73	80	69	89	/	70	80	30	30

Gainesville	70 79 66 83 / 70 80 40 30
Macon	72 77 69 85 / 70 90 60 20
Rome	70 84 64 87 / 50 60 20 20
Peachtree City	70 79 64 85 / 70 80 30 20
Vidalia	74 79 71 83 / 60 100 80 30

.FFC WATCHES/WARNINGS/ADVISORIES...

Flood Watch from Wednesday morning through late Wednesday night for GAZ039-050-051-059>062-071>076-080>086-091>098-103>113.

Tropical Storm Watch for GAZ085-086-096>098-105-107.

Tropical Storm Warning for GAZ106-108>113.

8.0 NWS Inflight Weather Advisories

Inflight Aviation Weather Advisories are forecasts that advise en route aircraft of the 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) at the various Air Route Traffic Control Centers (ARTCCs). There are four basic types of inflight aviation weather advisories: the Significant Meteorological Information (SIGMET), the Convective SIGMET, the G-AIRMET, and the Center Weather Advisory (CWA). Inflight advisories serve to notify en-route pilots of the possibility of encountering hazardous flying conditions that 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 flight dispatcher to evaluate based on experience and the operational limits of the aircraft. Once inflight weather advisories are issued, they are broadcast by FAA air traffic controllers upon issuance and are available on inflight weather broadcasts.

The advisory's current at 1830 EDT from the NWS AWC SIGMET display are depicted in figure 32 with the approximate turbulence location marked by the red star. The NWS had a Convective SIGMET current for the area generally south and east of the turbulence location for thunderstorms, which implies the potential for severe and greater turbulence in and near the convection. Convective SIGMET 17E was issued at 1755 EDT for an area of thunderstorms, with the advisory polygon expected to move northward at 10 knots. The expected thunderstorm tops were above 45,000 ft.

During the period the Atlanta Center Weather Service Unit (CWSU) issued no CWA's or Meteorological Impact Statements (MIS) during the period. There were also no relevant AIRMETs current for turbulence or low-level wind shear outside of any convection over the region during the period.

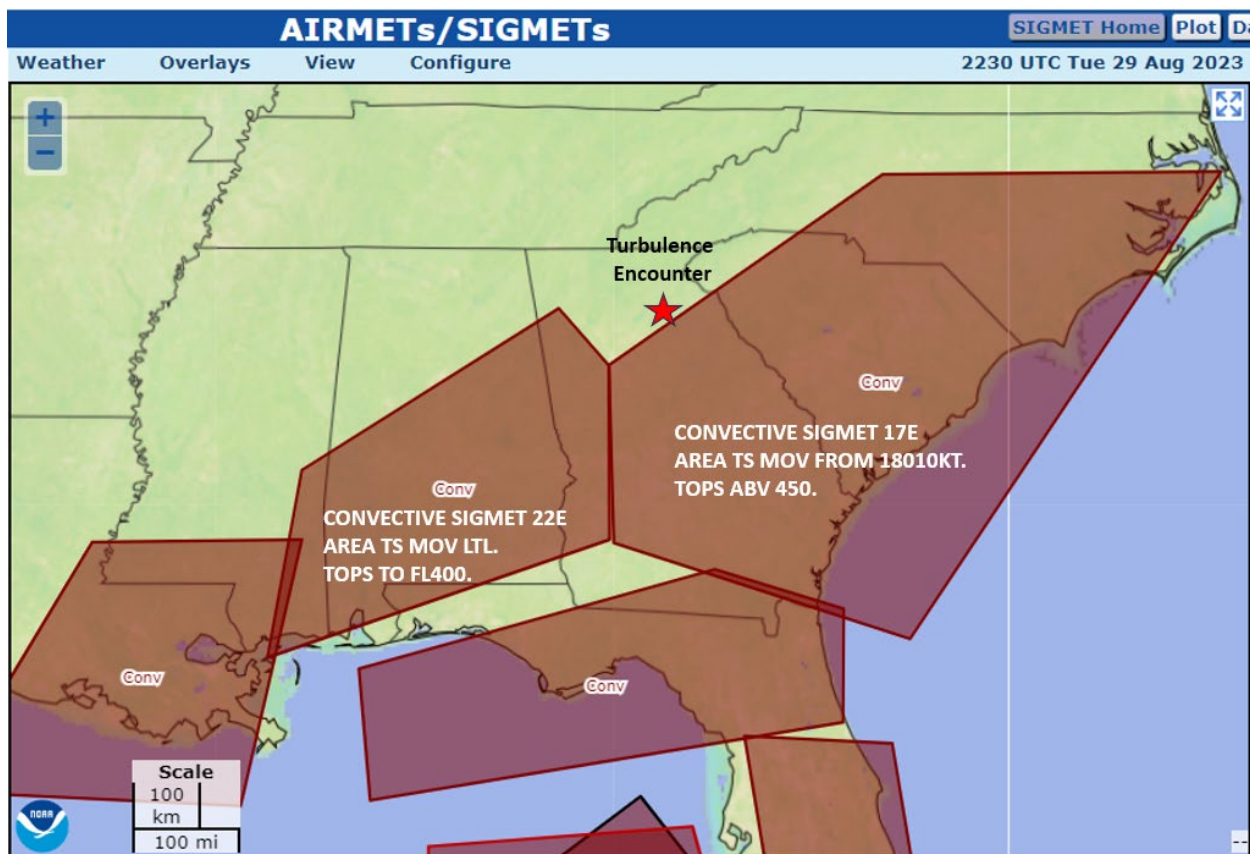


Figure 32 - Depiction of the Convective SIGMETs current at 1830 EDT and the turbulence site.

The full text of the relevant Convective SIGMET 17E was as follows.

WSUS31 KKCI 292155
SIGE
CONVECTIVE SIGMET 17E
VALID UNTIL 2355Z NC SC GA AND
NC FL SC GA CSTL WTRS
FROM 30WSW GSO-30SE ECG-70E CRG-10SSW PZD-ATL-30WSW GSO
AREA TS MOV FROM 18010KT. TOPS ABV FL450

9.0 Graphic Turbulence Guidance Nowcast

The National Center for Atmospheric Research (NCAR) located in Boulder, CO, provided a review of the Graphic Turbulence Guidance Nowcast (GTGN) presently being run on the NWS AWC testbed and waiting to be implemented at the NWS NCEP and is included as Attachment 2. The NCAR review included an EDR report from a Southwest B737 flying along a similar flight path immediately behind the Delta flight, which reported an EDR of 0.42 at 1833:20 EDT at 14,070 ft.

The GTGN provides a computer-generated four-dimensional forecast related to the expected intensity of atmospheric turbulence in convection provided in eddy dissipation rate (EDR)³⁴ as based on estimated vertical wind velocity or aircraft vertical acceleration to provide aircraft specific turbulence intensity values. The graphical turbulence grid is expressed in terms of Eddy Dissipation Rate (EDR) to the 1/3 power, i.e. $EDR = (m^2/s^3)^{1/3}$. NCAR defines the following EDR values to various aircraft weight classes and turbulence intensities, the Airbus A350 fits the heavy weight class. The estimated EDR thresholds below are multiplied by x100, as EDR values are depicted in the range from near 0 (typically smooth) to 100 (typically “extreme” for most aircraft).

GTG (Eddy Dissipation Rate)						
	L	MOD	SEV		E	Heavy
	LGT	MOD	SEV		EXTRM	Medium
	L	MOD	SEV		EXTRM	Light
10	20	40	60	80	100	
$(m^2/s^3)^{1/3}$						

10.0 Turbulence Reference Material

The International Civil Aviation Organization (ICAO) Annex 3 - Meteorological Services for International Air Navigation, Appendix 4 on Technical Specifications Related to Aircraft Observations and Reports, section 2.6.2 defines EDR and turbulence intensity for a medium-size weight category transport aircraft³⁵ under typical en-route conditions. ICAO standard EDR values are depicted in the range from near 0 (typically smooth) to 1 (typically “extreme” for most aircraft) in units of meters to the two-thirds power per second.

Turbulence shall be considered:

- severe when the peak value of the cube root of EDR exceeds 0.45;*
- moderate when the peak value of the cube root of EDR is above 0.20 and below or equal to 0.45;*
- light when the peak value of the cube root of EDR is above 0.10 and below or equal to 0.20; and*
- nil when the peak value of the cube root of EDR is below or equal to 0.10.*

³⁴ The EDR is an aircraft-independent measure of turbulence. However, the relationship between the EDR value and the perception of turbulence is a function of aircraft type, and the mass, altitude, configuration and airspeed of the aircraft. The EDR values given above describe the severity levels for a medium-sized transport aircraft under typical en-route conditions (i.e. altitude, airspeed and weight).

³⁵ ICAO only defined EDR values for a medium weight class aircraft.

The World Meteorological Organization (WMO) in their Aviation Hazards training guide define the turbulence intensities, aircraft response, vertical acceleration, passenger experience, and EDR values for various turbulence intensities for a medium weight category aircraft as follows. The EDR values in the WMO publication shows a slight larger variation in values, the main emphasis of the chart is with the vertical acceleration magnitudes used to discriminate the turbulence intensity.

Turbulence category	Aircraft response	Aircraft vertical acceleration magnitude (g)	Passenger experience	Approx $\epsilon^{1/3}$ ($\text{m}^{2/3} \text{s}^{-1}$) for B737 and B757 aircraft
Light	Momentarily causes slight, erratic changes in altitude and/or attitude (pitch, roll, yaw)	0.2–0.5	A slight strain against seat belts; unsecured objects may be displaced slightly; food service may be conducted with little difficulty walking	0.1–0.3
Moderate	Similar to light turbulence but greater intensity; changes in altitude, attitude, and/or airspeed occur; the aircraft remains in control at all times	0.5–1.0	Definite strain against seat belts; unsecured objects are dislodged; food service and walking are difficult	0.3–0.5
Severe	Large, abrupt changes in altitude, attitude, and/or airspeed; aircraft may be momentarily out of control	1.0–2.0	Occupants are forced violently against seat belts; unsecured objects are tossed about; food service and walking are impossible	0.5–0.7
Extreme	The aircraft is violently tossed about and is practically impossible to control; it may cause structural damage	> 2.0	Truly frightening	> 0.7

Figure 33 - WMO Turbulence Intensity Chart from light to extreme with aircraft and passenger response, aircraft vertical accelerations magnitude (g's), and eddy dissipation rate (EDR) for a medium weight category aircraft.

Light: Effects are less than those of moderate intensity.

Moderate: There may be moderate changes in aircraft attitude and/or height but the aircraft remains in control at all times. Air speed variations are usually small. Changes in accelerometer readings of 0.5-1.0g at the aircraft's center of gravity. Occupants feel strain against seat belts. There is difficulty in walking. Loose objects move about.

Severe: Abrupt changes in aircraft attitude and/or height. The aircraft may be out of control for short periods. Air speed variations are usually large. Changes in accelerometer readings greater than 1.0 g at the aircraft's center of gravity as severe. Occupants are forced violently against seat belts. Loose objects are tossed about.

Extreme: Effects are more pronounced than for severe intensity.

F. LIST OF ATTACHMENTS

Attachment 1 - Delta Air Lines Turbulence Review

Attachment 2 - NCAR Graphic Turbulence Guidance Nowcast (GTGN) Review

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