



NATIONAL TRANSPORTATION SAFETY BOARD

Office of Aviation Safety
Washington, D.C. 20594

April 19, 2017

Group Chairman's Factual Report

METEOROLOGY

DCA16LA214

Table Of Contents

A.	ACCIDENT	3
B.	METEOROLOGY GROUP	3
C.	SUMMARY	3
D.	DETAILS OF THE INVESTIGATION	3
E.	FACTUAL INFORMATION	4
1.0	Synoptic Conditions.....	4
2.0	Weather Radar	6
3.0	Lightning.....	15
4.0	Pilot Reports.....	15
5.0	Upper Air Data.....	16
6.0	Satellite Imagery	18
7.0	Surface Observations	19
8.0	SIGMETs	22
9.0	Center Weather Service Unit Products	23
10.0	Additional Information	23
F.	LIST OF ATTACHMENTS	25

A. ACCIDENT

Location: Waco, Texas
Date: August 17, 2016
Time: about 1217 central daylight time (1717 UTC)¹
Airplane: Boeing 737-924; N37408

B. METEOROLOGY GROUP

Mike Richards
Group Chairman
Senior Meteorologist
Operational Factors Division (AS-30)
National Transportation Safety Board

Tim Matuszewski
Group Member
Senior Manager - Domestic Air Traffic Systems
United Network Operations Control
United Airlines

C. SUMMARY

On August 17, 2016, about 1215 central daylight time (CDT), United Airlines flight 1945, a Boeing B737-924, N37408, while navigating around convection, encountered moderate turbulence descending out of 37,000 feet above mean sea level (msl), resulting in serious injury to one crewmember. The flight notified air traffic control and company, and landed without further incident. The flight was operating under 14 *Code of Federal Regulations* Part 121 as a regularly scheduled passenger flight from Seattle-Tacoma International Airport to George Bush Intercontinental Airport. Day instrument meteorological conditions prevailed at the time of the accident.

D. DETAILS OF THE INVESTIGATION

The National Transportation Safety Board's meteorological specialist traveled to United Airlines headquarters in support of this accident investigation, and gathered additional weather data remotely. Unless otherwise noted, all times are in CDT for August 17, 2016 (based upon the 24-hour clock), directions are referenced to true north, distances are in nautical miles and heights are above msl.

Coordinates used for the accident location: 30.989685° north latitude, 97.02713° west longitude, at an altitude of about FL290.²

¹ UTC – abbreviation for Coordinated Universal Time

² Flight Level (FL) - a standard nominal altitude of an aircraft, in hundreds of feet. This altitude is calculated from the

E. FACTUAL INFORMATION

1.0 Synoptic Conditions

The National Weather Service (NWS) Surface Analysis Chart for 1300 CDT is presented in figure 1. A WSR-88D regional radar composite reflectivity mosaic obtained from the National Centers for Environmental Information (NCEI) for 1215 CDT (figure 2) identified extensive light to intense levels of reflectivity across much of eastern Texas, including the accident area.

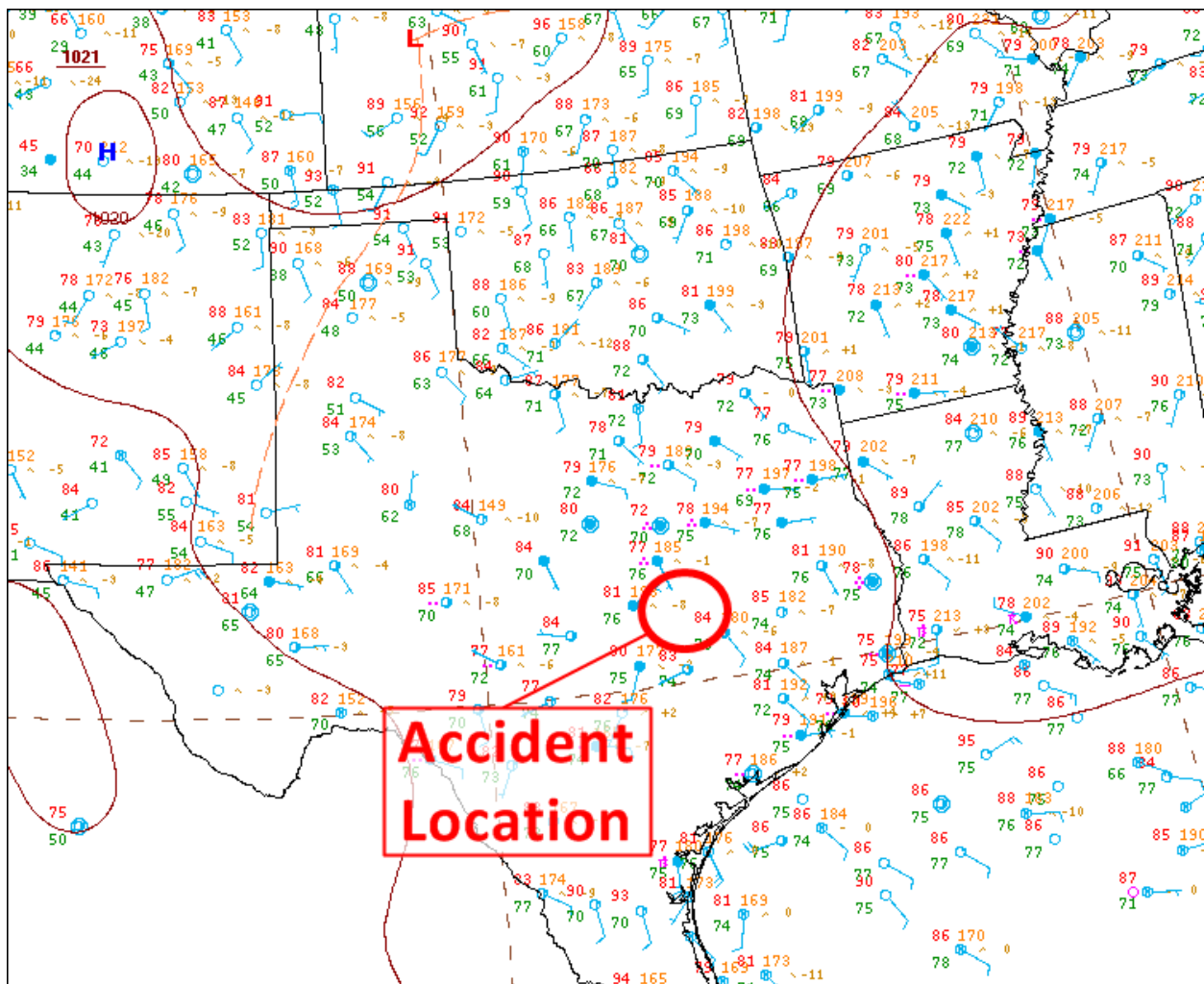


Figure 1 - NWS Surface Analysis Chart for 1300 CDT.

international standard pressure datum of 1013.25 hPa (29.92 in Hg), the average sea level pressure, and therefore is not necessarily the same as the aircraft's true altitude either above mean sea level or above ground level.

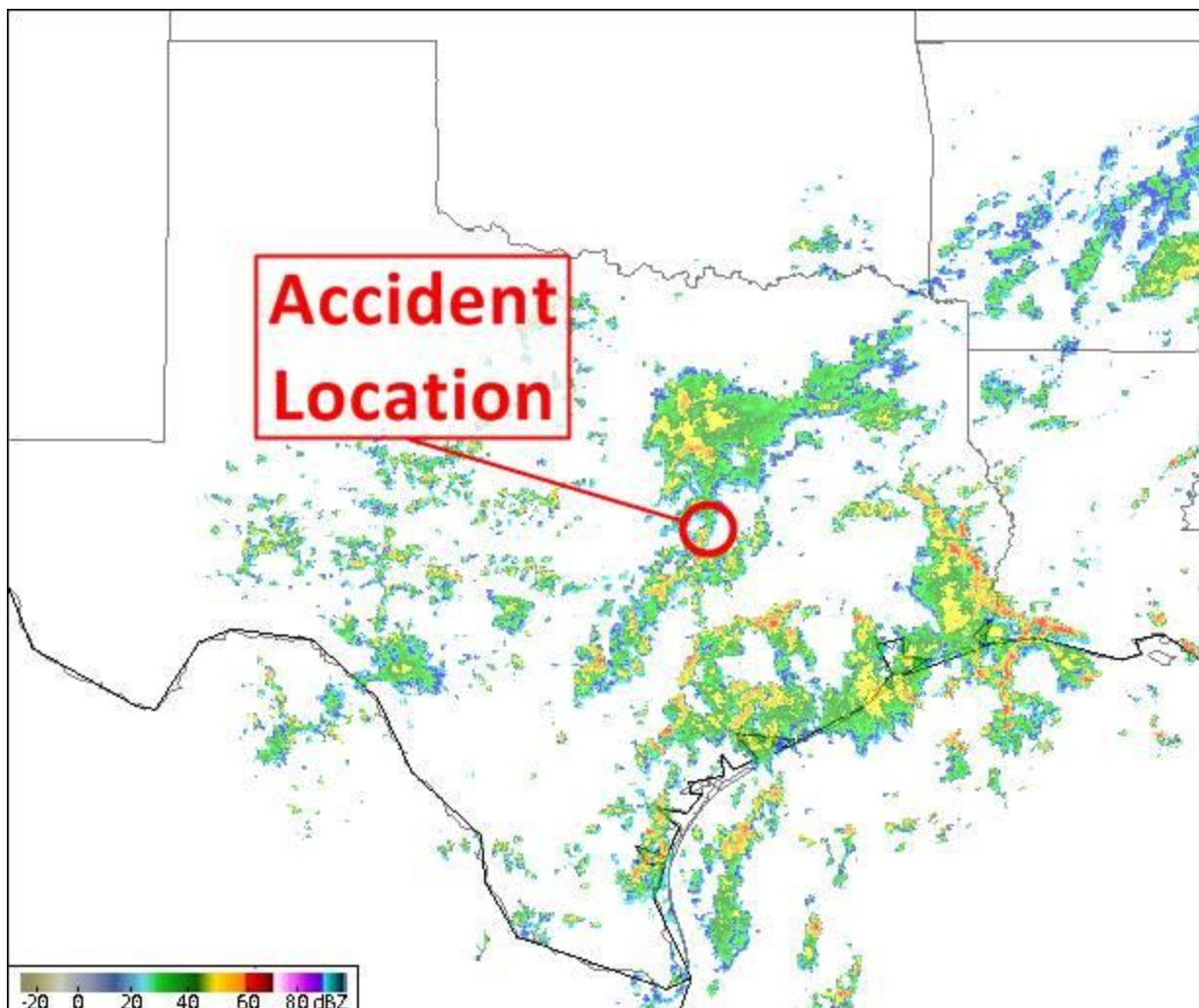


Figure 2 – NCEI WSR-88D mosaic from 1215 CDT.

2.0 Weather Radar

WSR-88D Level-II weather radar imagery from Fort Hood, Texas (KGRK), are presented in figures 3-6. KGRX was located approximately 24 miles southwest of the accident site at an elevation of 538 feet. Assuming standard refraction and considering the 0.95° beam width for the WSR-88D radar beam, the KDMX 0.52° and 10.0° tilts would have “seen” altitudes above the accident location of between about 1,050 and 3,450 feet msl and between about 25,000 and 27,500 feet msl, respectively.

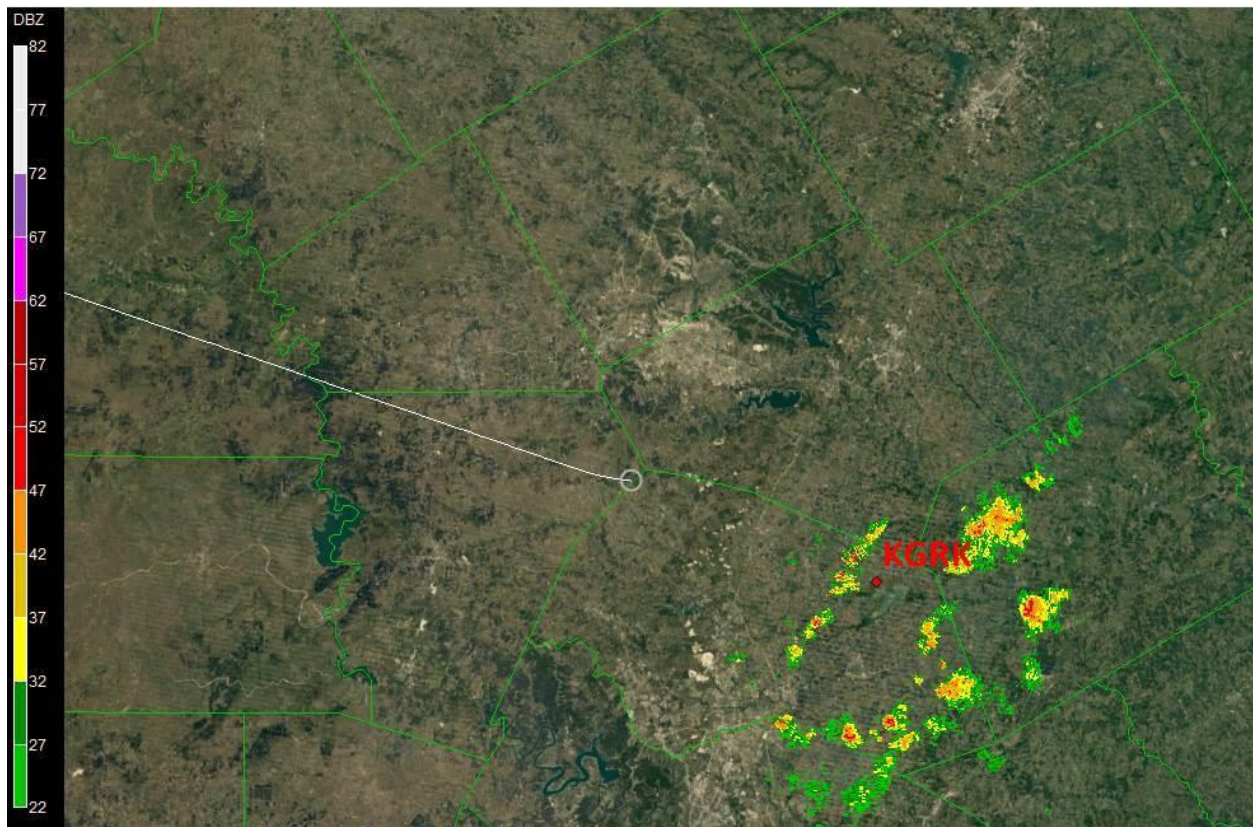


Figure 3 – KGRK 10.0° Level-II reflectivity product from a sweep initiated at 1211:46 CDT. Accident flight path denoted by white line with aircraft location at white circle at 1212:02 CDT. Reflectivity values less than 22 dBZ have been masked.

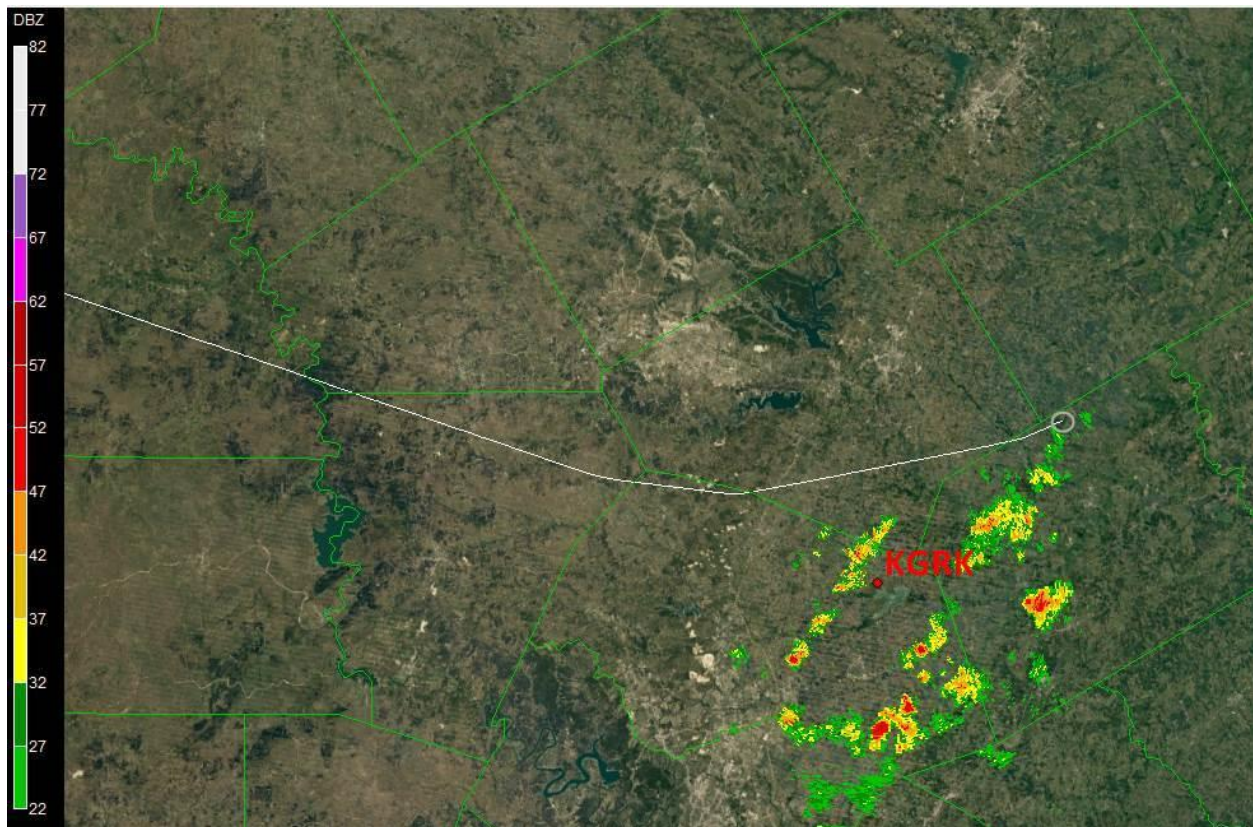


Figure 4 – KGRK 10.0° Level-II reflectivity product from a sweep initiated at 1216:47 CDT. Accident flight path denoted by white line with aircraft location at white circle at 1217:22 CDT (turbulence event). Reflectivity values less than 22 dBZ have been masked.

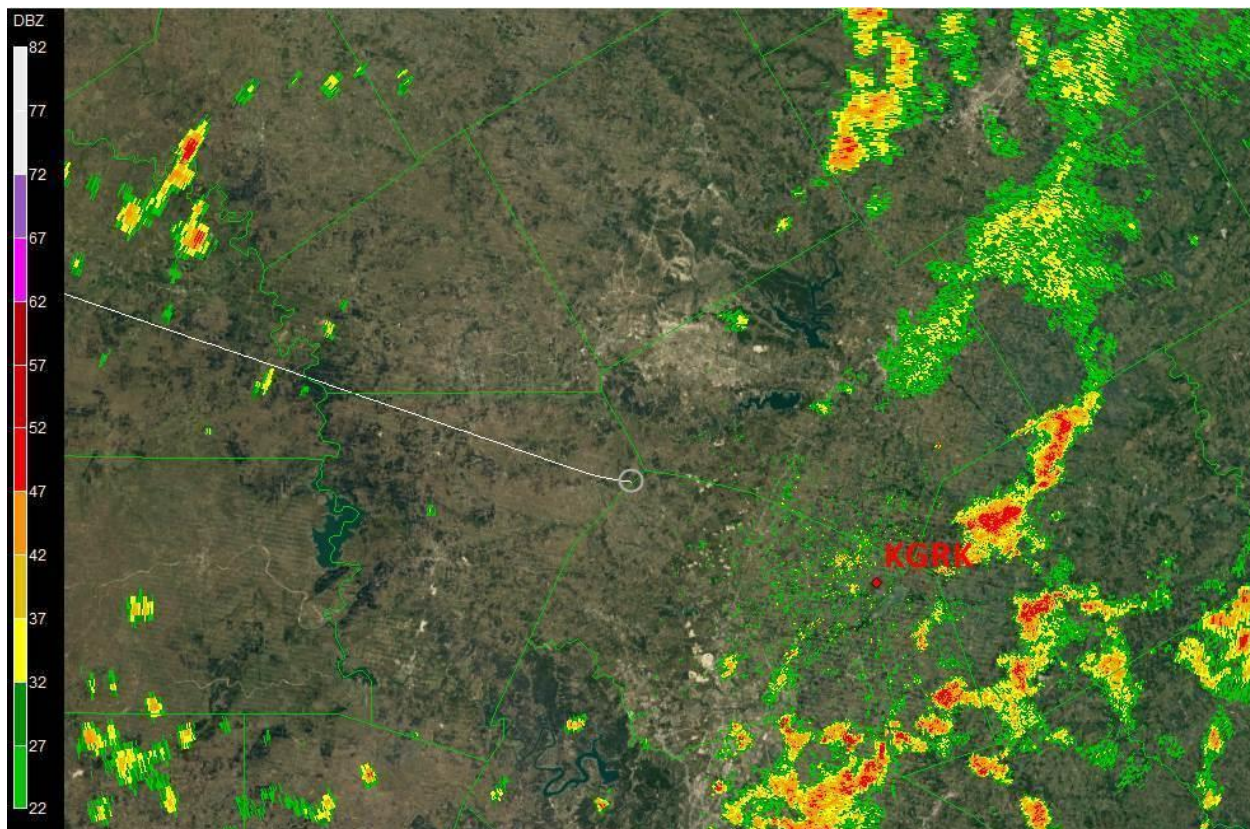


Figure 5 – KGRK 0.52° Level-II reflectivity product from a sweep initiated at 1208:10 CDT. Accident flight path denoted by white line with aircraft location at white circle at 1212:02 CDT. Reflectivity values less than 22 dBZ have been masked.

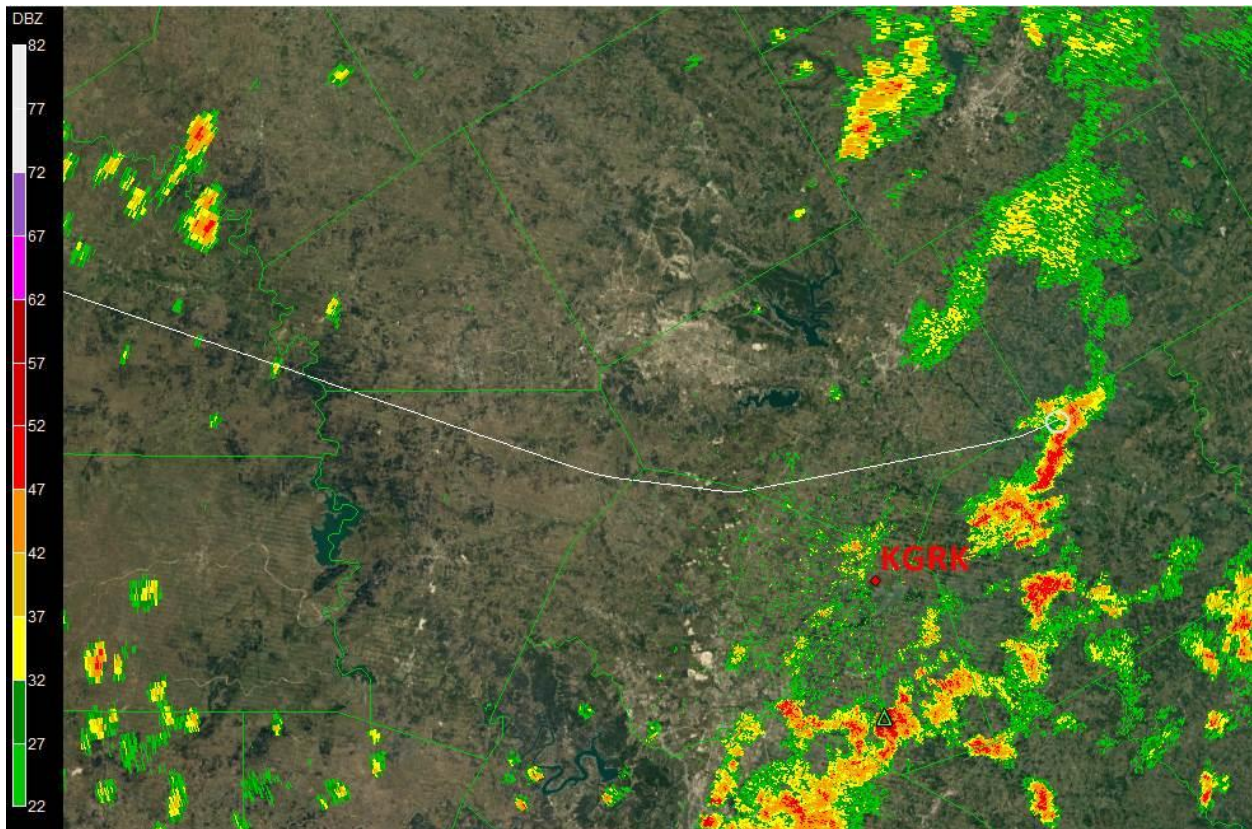


Figure 6 – KGRK 0.52° Level-II reflectivity product from a sweep initiated at 1213:18 CDT. Accident flight path denoted by white line with aircraft location at white circle at 1217:22 CDT (turbulence event). Reflectivity values less than 22 dBZ have been masked.

Figures 7-11 are pictures of a replay of the Houston Air Route Traffic Control Center (ARTCC) Weather and Radar Processor (WARP)³ radar mosaic applicable to the time surrounding the accident. Exact timestamps and altitude composite for these WARP screens are not known, however the accident aircraft's (United #1945) location can be identified in these images. The turbulence event occurred around the time of figure 10. "Precipitation" intensities are "moderate" (blue color), "heavy" (green/black "checkerboard" color) and "extreme" (light green color). Altitude composite is not known.

³ WARP – A system that provides real-time, predictive and strategic weather information presented in an integrated manner in the National Airspace System.



Figure 7 – Screenshot of the Houston ARTCC WARP replay for a time close to the accident time. The accident airplane is “UAL1945.”



Figure 8 – Screenshot of the Houston ARTCC WARP replay for a time close to the accident time. The accident airplane is “UAL1945.”



Figure 9 – Screenshot of the Houston ARTCC WARP replay for a time close to the accident time. The accident airplane is “UAL1945.”



Figure 10 – Screenshot of the Houston ARTCC WARP replay for a close to the accident time. The accident airplane is “UAL1945.”



Figure 11 – Screenshot of the Houston ARTCC WARP replay for a time close to the accident time.

3.0 Lightning

According to Earth Networks, the Earth Networks Total Lightning Network (ENTLN) did not detect any lightning within a 50-mile radius around the accident site between 1130 and 1230 CDT (inclusive).

Archive data from the Federal Aviation Administration's Corridor Integrated Weather System (CIWS; figure 12), which presents cloud-to-ground lightning flash detections from the National Lightning Detection Network, identified lightning activity within about 50 miles of the accident location between 1209 and 1215 CDT.

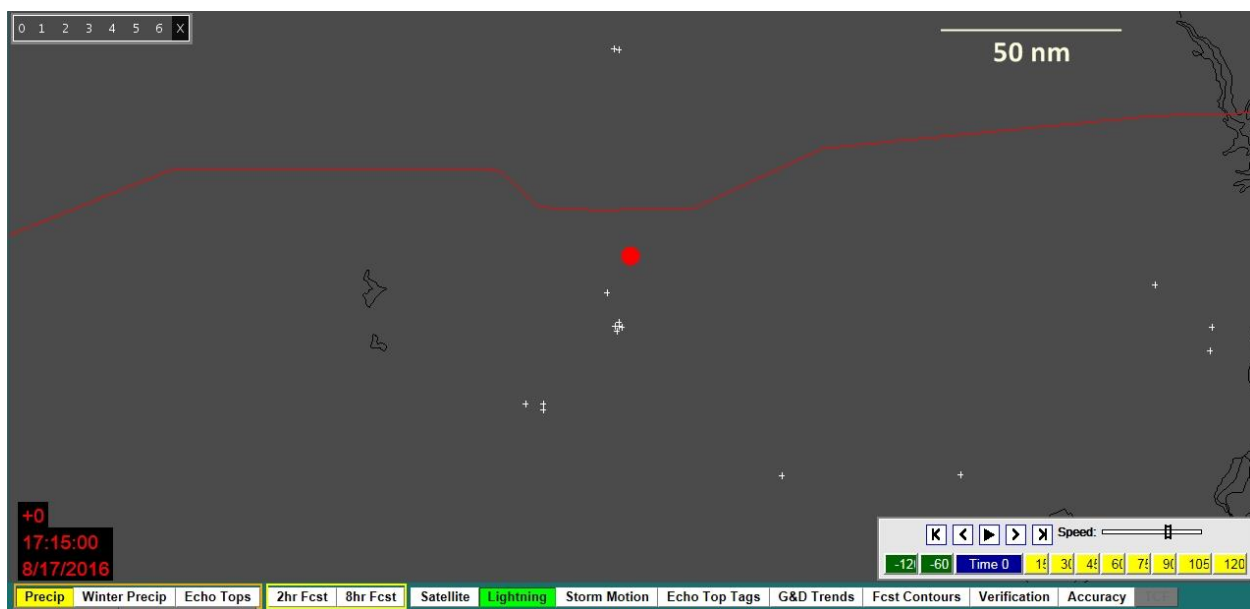


Figure 12 – Archive CIWS display from 1215 CDT. Red circle denotes accident location. White “+” symbols denote lightning activity.

4.0 Pilot Reports

There were no publicly disseminated pilot reports (PIREPs)⁴ made within one hour of the accident time near the accident site.

At 1103 CDT, an MD-90 aircraft at 14,000 feet located 15 miles away on the 135° radial from Draughton-Miller Central Texas Regional Airport (TPL) in Temple, Texas, reported rain and moderate chop between 14,000 and 17,000 feet. This report was disseminated by the Houston ARTCC.

TPL UA /OV TPL135015 /TM 1603 /FL140 /TP MD90 /WX RA /TB MOD CHOP
140-170 /RM FM ZHU AWC-WEB=

⁴ Only pilot reports with the WMO header UBTX** were considered.

5.0 Upper Air Data

A High-Resolution Rapid Refresh (HRRR) model⁵ sounding (figure 13) for the accident location at 1200 CDT was retrieved from the National Oceanic and Atmospheric Administration's (NOAA) Air Resources Laboratory. Near the surface, the wind was from the southwest at about 5 knots. Above this level the wind veered with height and increased in magnitude to a southwest wind at about 15 knots near 13,000 feet. Above this level, the wind remained generally southeast and relatively light (below 7 knots) through 30,000 feet. Calculations made by the Rawinsonde OBservation Program did not yield any significant areas of non-convective turbulence for this atmosphere. The freezing level was at about 15,600 feet and the tropopause was located above 35,000 feet.

The most-unstable Convective Available Potential Energy (CAPE)⁶ parameter was 1,323 Joules/kilogram (from 1004 hectopascals [hPa]). The Lifting Condensation Level⁷ (LCL) and Level of Free Convection⁸ (LFC) were calculated to be 720 feet. Maximum vertical velocity (MVV) for this atmosphere was calculated as 51 meters/second (about 10,040 feet per minute).⁹ Downdraft CAPE (DCAPE; 6 kilometers agl)¹⁰ was measured at 405 Joules/kilogram.

⁵ 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.

⁶ Convective Available Potential Energy - 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.

⁷ Lifting Condensation Level - The level at which a parcel of moist air lifted dry-adiabatically would become saturated.

⁸ Level of Free Convection - The level at which a parcel of air lifted dry-adiabatically until saturated and saturation-adiabatically thereafter would first become warmer than its surroundings in a conditionally unstable atmosphere. On a thermodynamic diagram the level of free convection is given by the point of intersection of the process curve, representing the process followed by the ascending parcel, and the sounding curve, representing the lapse rate of temperature in the environment.

⁹ MVV is not usually considered a realistic estimate for maximum vertical velocity in a storm. Anecdotes suggest considering a value of MVV/2, however it is not well understood when or where such a half-value should be applied.

¹⁰ The DCAPE can be used to estimate the potential strength of rain-cooled downdrafts within thunderstorm convection, and is similar to CAPE. Larger DCAPE values are associated with stronger downdrafts.

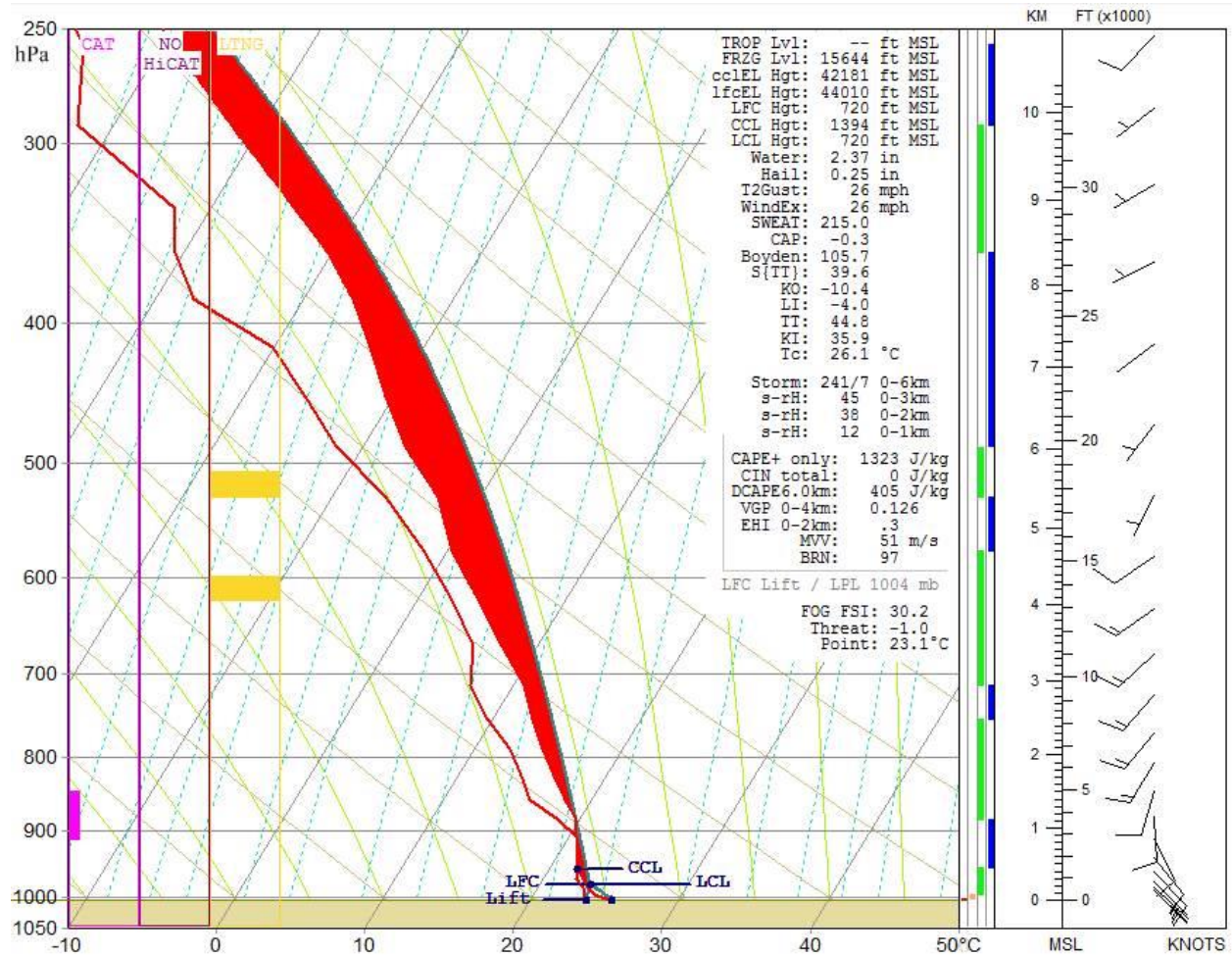


Figure 13 – HRRR model sounding data in SkewT/LogP format for 1200 CDT at the accident site, surface to 250 hPa.

6.0 Satellite Imagery

Geostationary Operational Environmental Satellite (GOES)-13 visible ($0.63\mu\text{m}$) and infrared ($10.7\mu\text{m}$) data were obtained from an archive at the Space Science Engineering Center at the University of Wisconsin-Madison. Imagery from 1215 CDT is presented in figures 14 and 14. The GOES-13 infrared cloud-top temperatures varied between -25°C and -58°C in the immediate area of the accident location. When considering the HRRR model sounding, -25°C corresponded to cloud top heights of about 31,000 feet and -58°C was well above 35,000 feet. It should be noted that these figures have not been corrected for any parallax error.

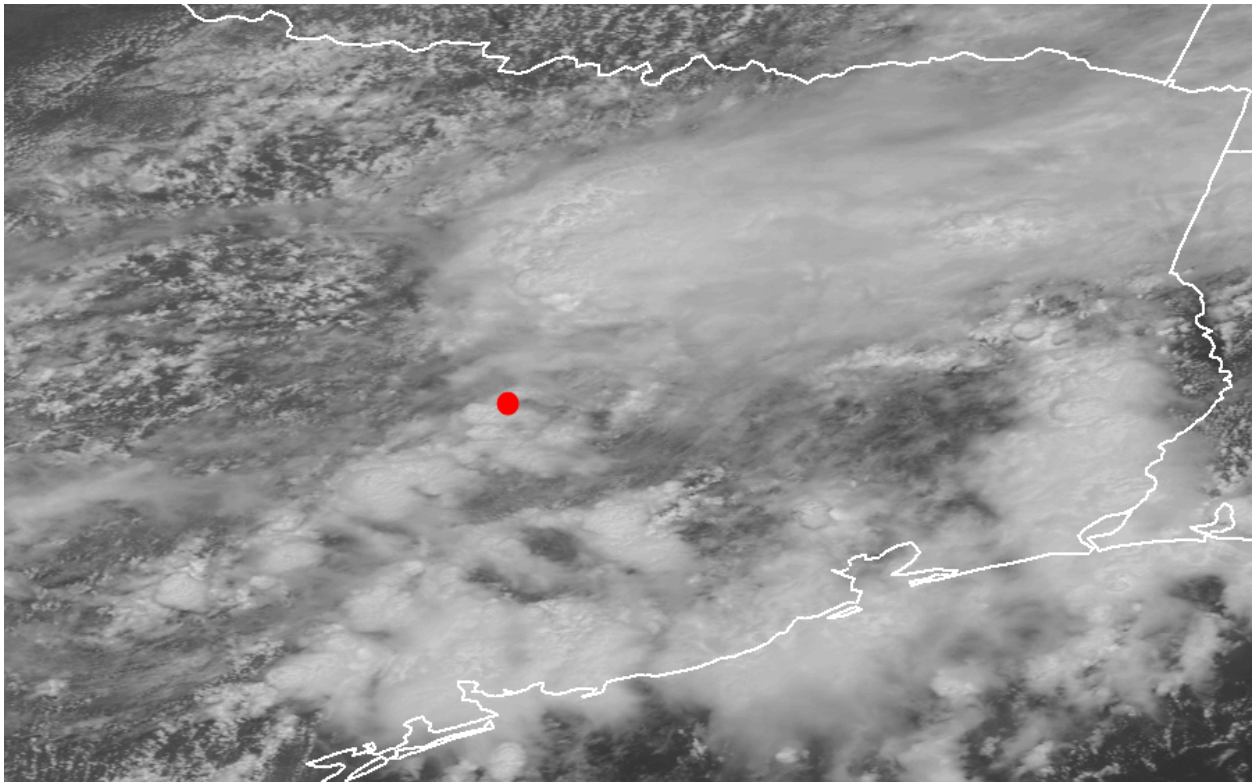


Figure 14 – GOES-13 visible imagery from 1215 CDT. Accident location denoted by red dot.

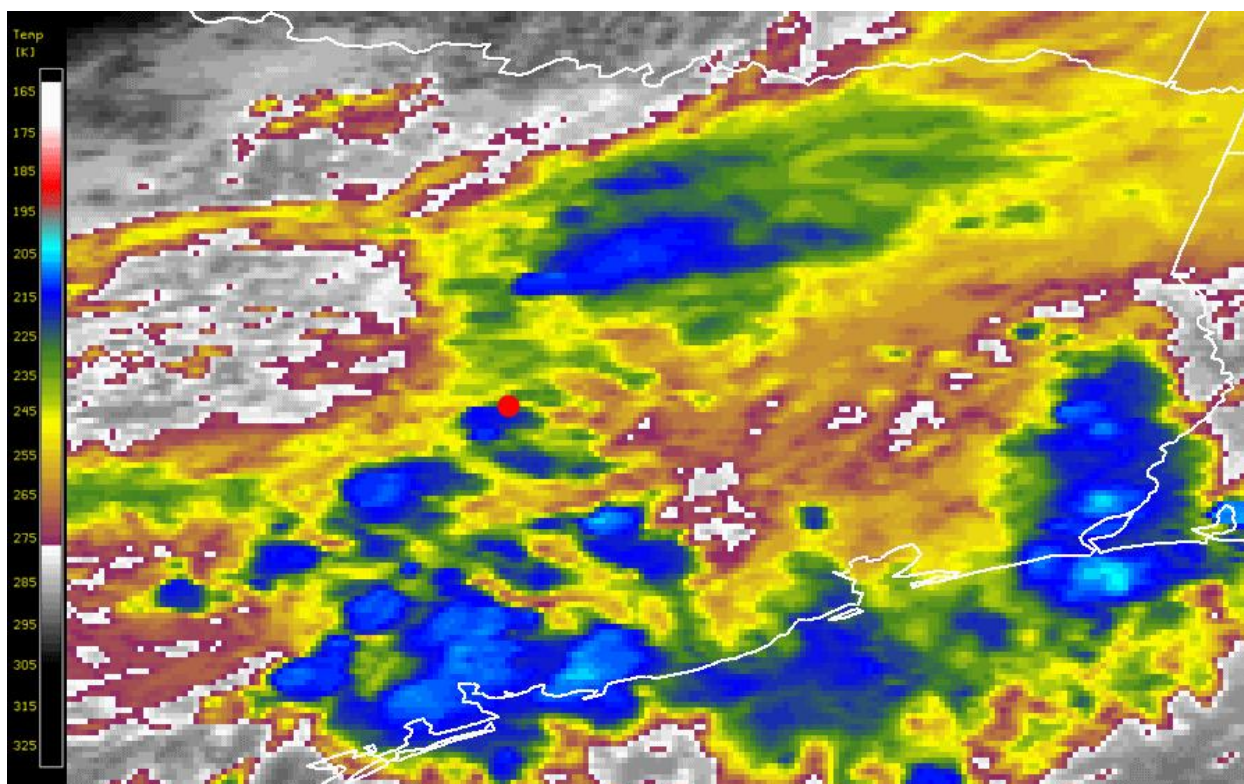


Figure 15 – GOES-13 infrared imagery from 1215 CDT. Accident location denoted by red dot.

7.0 Surface Observations

An Automated Weather Observing System (AWOS) was located at Cameron Municipal Airpark (T35)¹¹ in Cameron, Texas, which was located about 7 miles south-southeast of the accident location at an elevation of 402 feet. Automated reports from T35 during the times surrounding the accident time are presented here:

[1055 CDT] METAR KT35 171555Z AUTO 14005KT 10SM BKN007 OVC014 26/25
A3011 RMK AO2 T02630246=

[1115 CDT] METAR KT35 171615Z AUTO 13004KT 10SM BKN009 OVC012 27/25
A3011 RMK AO2 LTG DSNT N T02650247=

[1135 CDT] METAR KT35 171635Z AUTO 12005KT 10SM BKN009 OVC015 27/25
A3010 RMK AO2 LTG DSNT N T02700247=

¹¹ The National Weather Service (NWS) uses the 4-digit International Civil Aviation Organization (ICAO) format for station identifiers (as seen in the body of some formatted weather observations). This report uses the 3-digit International Air Transport Association format for station identification, which does not use the geographic designating digit (“K” for stations in the continental U.S. and “P” for U.S. stations in Alaska and the Pacific region) as found in the ICAO format.

**[1155 CDT] METAR KT35 171655Z AUTO 13005KT 10SM OVC012 28/25 A3009
RMK AO2 LTG DSNT SW T02790251=**

**[1215 CDT] METAR KT35 171715Z AUTO 13006KT 10SM TS BKN012 OVC018
28/25 A3009 RMK AO2 LTG DSNT SW THRU N T02800247=**

**[1235 CDT] METAR KT35 171735Z AUTO 13004KT 10SM TS BKN014 BKN020
OVC034 28/25 A3009 RMK AO2 LTG DSNT SW T02750246=**

At 1155 CDT, T35 reported a wind from 130° at 5 knots, visibility of ten statute miles or greater, ceiling overcast at 1,200 feet above ground level (agl), temperature of 28° Celsius (C) and a dew point temperature of 25°C, altimeter setting of 30.09 inches of mercury; remarks included: station with a precipitation discriminator, lightning more than 10 miles away to the southwest.

At 1215 CDT, T35 reported a wind from 130° at 6 knots, visibility of ten statute miles or greater, thunderstorm, ceiling broken at 1,200 feet agl, overcast cloud base at 1,800 feet agl, temperature of 28°C and a dew point temperature of 25°C, altimeter setting of 30.09 inches of mercury; remarks included: station with a precipitation discriminator, lightning more than 10 miles away to the southwest through north.

At 1235 CDT, T35 reported a wind from 130° at 4 knots, visibility of ten statute miles or greater, thunderstorm, ceiling broken at 1,400 feet agl, broken clouds at 2,000 feet agl, overcast cloud base at 3,400 feet agl, temperature of 28°C and a dew point temperature of 25°C, altimeter setting of 30.09 inches of mercury; remarks included: station with a precipitation discriminator, lightning more than 10 miles away to the southwest.

An AWOS was located at TPL, which was located about 22 miles west-northwest of the accident location at an elevation of 682 feet. Automated reports from TPL during the times surrounding the accident time are presented here:

**[1057 CDT] SPECI KTPL 171557Z AUTO 13009KT 3SM -RA BR FEW007 BKN025
OVC032 24/23 A3012 RMK AO2 P0000=**

**[1151 CDT] METAR KTPL 171651Z AUTO 11004KT 8SM -RA SCT017 BKN028
OVC060 24/23 A3011 RMK AO2 LTG DSNT S RAE08B25 SLP200
P0001 T02390233=**

**[1203 CDT] SPECI KTPL 171703Z AUTO 14005KT 10SM FEW017 SCT028 24/23
A3010 RMK AO2 RAE1659 P0000=**

**[1247 CDT] SPECI KTPL 171747Z AUTO 09006KT 10SM SCT009 26/24 A3010 RMK
AO2 LTG DSNT SE RAE1659 P0000=**

At 1151 CDT, TPL reported a wind from 110° at 4 knots, visibility of eight statute miles, light rain, scattered clouds at 1,700 feet agl, ceiling broken at 2,800 feet agl, overcast cloud base at 6,000 feet agl, temperature of 24°C and a dew point temperature of 23°C, altimeter setting of 30.11 inches of mercury; remarks included: station with a precipitation discriminator, lightning more

than 10 miles away to the south, rain ended at 1108 CDT and rain began at 1125 CDT, 0.01 inches of precipitation since 1057 CDT.

At 1203 CDT, TPL reported a wind from 140° at 5 knots, visibility of ten statute miles or greater, few clouds at 1,700 feet agl, scattered clouds at 2,800 feet agl, temperature of 24°C and a dew point temperature of 23°C, altimeter setting of 30.10 inches of mercury; remarks indicated: station with a precipitation discriminator, rain ended at 1159 CDT, trace precipitation.

An Automated Surface Observing System (ASOS) was located at the accident aircraft's destination airport George Bush Intercontinental/Houston Airport (IAH) in Houston, Texas, which was located about 105 miles southeast of the accident location at an elevation of 96 feet. Undecoded augmented reports from IAH during the times surrounding the accident time are presented here:

[1053 CDT] METAR KIAH 171553Z 12004KT 10SM -RA FEW010 BKN040 BKN160
OVC250 27/24 A3011 RMK AO2 RAB36 SLP196 CB DSNT S-SW MOVG
N P0000 T02670239=

[1153 CDT] METAR KIAH 171653Z 14011KT 10SM -RA BKN018CB BKN038
OVC160 28/24 A3011 RMK AO2 RAE11B51 SLP197 CB SE-S MOVG N
P0000 T02780244=

[1207 CDT] SPECI KIAH 171707Z 14017KT 10SM R27/1800VP6000FT -TSRA
FEW007 BKN018CB OVC038 27/24 A3012 RMK AO2 TSB07 VIS NE-SE
1 IN +SHRA OCNL LTGICCG NE-SE TS NE-SE MOVG N P0000
T02670244=

[1225 CDT] SPECI KIAH 171725Z 14012KT 10SM -TSRA FEW007 SCT018CB
BKN038 OVC160 26/24 A3012 RMK AO2 TSB07 OCNL LTGICCG N-NE
TS N-NE MOVG N P0000 T02610239=

[1253 CDT] METAR KIAH 171753Z 13012KT 10SM FEW011 SCT038 BKN100
OVC180 27/24 A3010 RMK AO2 RAE26 TSB07E53 SLP194 TS MOVD N
CB SHRA DSNT N-NE MOVG N P0000 60007 T02720244 10283 20239
50003=

8.0 SIGMETs

There were no non-convective Significant Meteorological Information (SIGMET) advisories active for the accident location at the accident time.

At 1155 CDT, the AWC issued the following convective SIGMET, which was valid for two hours (also see figure 16) and active for the accident location at the accident time. It advised of an area of embedded thunderstorms moving from 180° at 10 knots, with tops above FL450.

WSUS32 KKCI 171655
SIGC
-MKCC WST 171655
CONVECTIVE SIGMET 59C
VALID UNTIL 1855Z
TX
FROM 10SW TTT-70NNW IAH-40SE SAT-20S SAT-10SW TTT
AREA EMBD TS MOV FROM 18010KT. TOPS TO FL450.

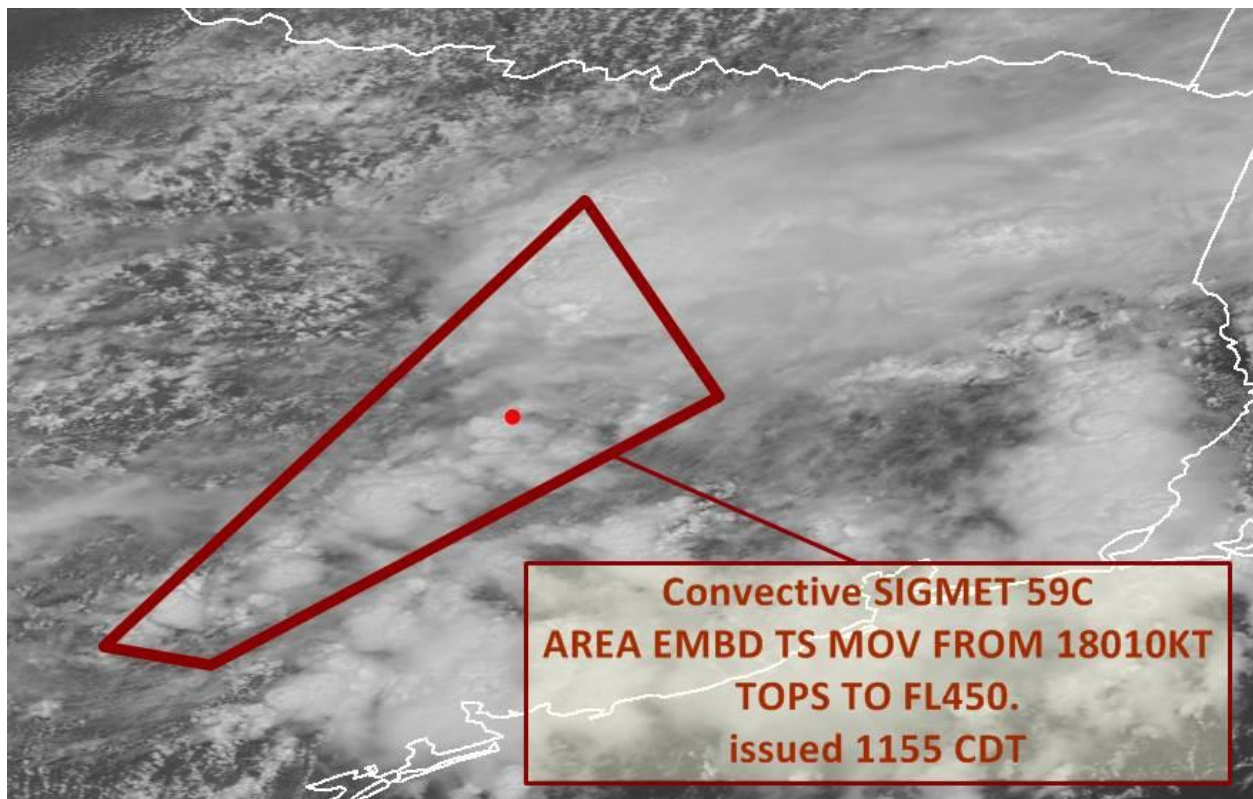


Figure 16 – Boundaries of convective SIGMET 59C issued at 1155 CDT. Red dot denotes accident location.

One hour earlier at 1055 CDT, the AWC issued the following convective SIGMET, which was valid for two hours and active for the accident location at the accident time. It advised of an area of embedded thunderstorms moving from 180° at 10 knots, with tops above FL450.

WSUS32 KPCI 171555
SIGC
-MKCC WST 171555
CONVECTIVE SIGMET 57C
VALID UNTIL 1755Z
TX
FROM 10SW TTT-60ENE ACT-10ESE CWK-60W ACT-10SW TTT
AREA EMBD TS MOV FROM 18010KT. TOPS TO FL450.

9.0 Center Weather Service Unit Products

There were no Center Weather Advisories or Meteorological Impact Statements issued by the Center Weather Service Units (CWSU) at the Fort Worth and Houston ARTCCs that were active for the accident location at the accident time.

10.0 Additional Information

An analysis of the weather conditions associated with this accident was provided by United Airlines and is found in Attachment 1.

United Airlines provided written responses to NTSB weather-related questions. These responses are found in Attachment 2. In their response to NTSB Question 2, United indicated that they had a contract with Panasonic, Inc. for weather support; however, in March 2017, United indicated that as of 2017, they no longer have a contract with Panasonic (the contract was allowed to expire at the end of 2016).

Weather-related training modules provided by United are found in Attachments 3-5.

At the request of the NTSB, scientists from the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS)¹² reviewed weather radar data from the region and provided imagery of echo

¹² The Cooperative Institute for Mesoscale Meteorological Studies is a research organization created in 1978 by a cooperative agreement between the University of Oklahoma and the National Oceanic and Atmospheric Administration.

tops¹³, 8.5 kilometer height reflectivity¹⁴, composite reflectivity¹⁵ and storm top height, which are found in Attachments 6, 7, 8 and 9, respectively. Flight path (airplane symbols) in these images was generated using a publicly-available¹⁶ approximation of the accident aircraft's flight path.

A general description of CIMMS' "Z_{dr} column" identification algorithm¹⁷ and their analysis of meteorological conditions associated with this event using this algorithm is available in a video file in the NTSB docket for this accident. According to a CIMMS scientist, *"The environment was not supportive of intense thunderstorms. Rather, it was quite a 'tropical' environment, one in which I'd expect to see deep/tall but not-particularly-strong storms. Given the relatively weak updrafts, I don't see any indications of persistent, deep ZDR columns near the flight's path."* The scientist further stated, *"I have a hard time detecting any updraft signatures in the polarimetric radar data, though that's not surprising considering the tropical environment. Although an aviation hazard, the updrafts in storms in these tropical environments tend to be quite a bit weaker, which tends to reduce the number of large rain drops in the updraft and, hence, our ability to see them in things such as ZDR columns. I've examined other features and signatures, but there's just not much there."*

¹³ An echo top is the radar indicated top (i.e., height) of an area of precipitation. Once the precipitation intensity drops below a threshold value (18 dBZ in Attachment 1) as the radar beam samples higher elevations of a storm or precipitation region, then the echo top is located. The cloud top will often extend above the echo top since clouds are more difficult to detect by radar.

¹⁴ A presentation of reflectivity values at a constant height of 8.5 kilometers (approximately)

¹⁵ Composite reflectivity shows the highest reflectivity value from each vertical column.

¹⁶ Taken from the Flightaware website (<http://flightaware.com/>).

¹⁷ The differential reflectivity (Z_{dr}) WSR-88d radar product shows the difference in returned energy between the horizontal and vertical pulses of the radar. Z_{dr} is defined as the difference between the horizontal and vertical reflectivity factors in dBZ units.

F. LIST OF ATTACHMENTS

Attachment 1 - Event analysis provided by United Airlines.

Attachment 2 - United Airlines' written responses to NTSB weather-related questions.

Attachment 3 - United Airlines recurrent training, Fall 2015, turbulence avoidance.

Attachment 4 - United Airlines recurrent training, Spring 2015, auto-PIREPs alerting & Graphical Turbulence Guidance.

Attachment 5 - United Airlines recurrent training, Spring 2016, convectively-induced turbulence.

Attachment 6 - Echo tops data provided by the Cooperative Institute for Mesoscale Meteorological Studies.

Attachment 7 - 8.5 kilometer height reflectivity data provided by the Cooperative Institute for Mesoscale Meteorological Studies.

Attachment 8 - Composite reflectivity data provided by the Cooperative Institute for Mesoscale Meteorological Studies.

Attachment 9 - Storm top height data provided by the Cooperative Institute for Mesoscale Meteorological Studies.

Submitted by:

Mike Richards
Senior Meteorologist

THIS PAGE INTENTIONALLY BLANK