APPENDIX D-METEOROLOGICAL INFORMATION/NCAR STUDY

Mesoscale analysis of the COMAIR-3272 crash of 9 January 1997

Ben C. Bernstein
Research Applications Program
National Center for Atmospheric Research
Boulder, CO 80307-3000
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1. Introduction

This discussion is to be considered in the context of the synoptic-scale weather data previously presented to the NTSB by NCAR. Here, the focus is placed on the mesoscale weather elements which are pertinent to the accretion of ice on Comair-3272 and on explaining the significant differences in icing reported by the pilots of four other aircraft which flew in close proximity to Comair-3272 within a 10 minute time window.

2. Analysis of radar data - overview

Regional radar images indicate widespread areas of snow across Michigan at 2000 and 2100 UTC, essentially to the north of the Ohio/Michigan border (see Figs. 1a, b). Along the edges of this area of snow, there were patches of lower reflectivity, which show up as "holes" in the echo pattern. These patches were evident near Detroit during the period in which the crash occurred. Close examination of the 0.5 degree scan from the Detroit NEXRAD (DTX) at 2049 UTC (Fig. 2a) shows widespread reflectivity of > 15 dBZ across much of the radar scope, with weaker echoes to the southeast and south of DTX. Patches of lower reflectivity are evident in these areas, with values of about 0 to 10 dBZ. One of these patches was in place from approximately 50 to 100 km to the south-southwest of DTX. A look at the 1.5 and 2.4 degree scans (Figs. 2b,c) indicates that reflectivity values decreased with height in this area. Comair-3272 was flying through this patch of lower reflectivity during the last 6 ½ minutes before the upset occurred. At 2050 UK, Comair-3272 was at an altitude of ~7000 ft (~2133 m) MSL and location of ~72 km from the DTX radar at ~200 degrees azimuth. Since the DTX radar is at an elevation of 360 m MSL, Comair-3272 was ~1733 m above the radar at a distance of 72 km, corresponding to an elevation angle of approximately 1.4 degrees. Reflectivity values at the location of the Comair were between -5 and + 10 dBZ on the 1.5 degree elevation scan and are relatively low compared to the 10-30 dBZ values within a swath of snow to the northwest and north.

Data from the DTX radar have been digitally interpolated to a 150 km by 150 km grid that encompasses the Comair's path of flight during the last ~8 minutes before the crash. Horizontal slices (CAPPIs) of radar data were created at 0.8 and 2.3 km MSL from DTX radar volumes which began at 2037, 2043 and 2049 UTC. These altitudes roughly approximate the height of the center of the 0.5 and

1.5 degree elevation DTX radar beams at the horizontal location of Comair-3272 at 2050 UTC (~72 km SSW of DTX). Superposition of the FAA radar-based tracks of Comair-3272 and several other aircraft on approach to Detroit on the 0.8 km CAPPI from 2049 UTC (Fig. 3a) indicate that these planes were flying on the southeastern edge of the large swath of precipitation where most of the reflectivity values were approximately 10 dBZ at 0.8km (~1.3 km below flight level). All of the aircraft passed through a patch of lower reflectivity during or just before the first of two turns on approach to Detroit. This patch will be discussed in further detail and related to the tracks of the aircraft in a later section of this report.

3. Comparison of surface observations with radar and sounding data

Data from several National Weather Service reporting stations in the vicinity of the crash have also been plotted on the gridded radar reflectivity map for 0.8 km MSL (Fig. 3a). All of the stations (DTW - Detroit MI, YIP - Ypsilanti/Detroit-Willow MI, ARB - Ann Arbor MI, JXN - Jackson MI, TOL - Toledo OH) were reporting snow at ~2050 UTC, but details in the observations reveal more information. DTW was reporting light snow and mist, visibility of 3/4 miles, broken clouds at 600 and 1200 feet and an overcast deck at 1700 feet. Reflectivity values over DTW were approximately 20 dBZ at this time, but as areas of lower reflectivity to the southwest moved over DTW, the visibility at the surface improved to 3 miles and the snow briefly stopped between 2149 and 2201 UTC (1649-1701 LST - see observer comments in Table 1a). Ice pellets were repotted at DTW about 2 ½ hours after the crash, from 2332 to 2347 UTC (1832-1847 LST). ARB was located on the northern edge of the patch, where reflectivity values were approximately 10 dBZ As the northern edge of the patch of low reflectivity reached ARB, the visibility temporarily rose from 1 mile (1953 UTC) to 4 miles (2053 UTC), then fell back to 2.5 miles (2121 UTC), then to 1.5 miles (2150 UTC), following the passage of the patch (see Table lb). This brief increase in visibility indicates that the intensity of the snow is likely to have decreased substantially within the northern edge of the patch. JXN was located to the northwest of the aircraft tracks, within areas of 15-20 dBZ reflectitity, reported continuous light snow, visibility values of 1 mile or less and overcast ceilings varying from 800 to 1700 feet.

The decrease in or cessation of snowfall in the areas of low reflectivity indicates that the snow-making process was less efficient there, thus allowing a greater opportunity for liquid cloud to exist. Several observations of pellets were made by surface stations (Detroit MI, Findlay OH) and individuals (a pilot at home in Mason City,MI reported pellets and described them as “not opaque, but not clear, either”; a fireman on his way to the crash scene reported pellets) around the Detroit area in the hours surrounding the crash. These observations indicate that either large drops and/or significant water contents were likely to exist within the cloud, possibly mixed with snow crystals in some locations. Any pellets which did occur were formed in an environment free of the melting process, since only subfreezing tempetatures were found in sounding data from both Detroit and Wilmington, Ohio for 0000 UTC on 10 January (see Tables 2a,b).

4. Comparison of aircraft tracks with radar data

FAA radar-based track data available for five different aircraft flying in the area near the time of the crash are plotted on the 0.8 km radar cross-section (Fig. 3a). The planes were as follows: Comair 3272 (Embraer 120, red line), NW 272 (DC 9, purple line), America West 50 (Airbus 320, green line), NW 483 (Boeing 757, blue line) and NW 208 (Airbus 320, brown line). Times for the locations of the aircraft are indicated with symbols on the plot. At 2050 UTC (circles in Fig. 3a), Comair-3272 was making a tum toward the southeast within the patch of low reflectivity, while America West 50 was just ahead of it and NW 272 was just behind it, NW 483 and NW 208 had passed through this area about 5 and 10 minutes earlier, respectively. In post-crash interviews, the pilots of these aircraft reported icing conditions varying from no icing (NW 483) to "the worst icing that (the pilot) had encountered all season" (NW 272). Although these planes flew through similar locations within about 10 minutes of each other, close inspection of the tracks and altitudes of the aircraft relative to the patch of low reflectivity reveals the source of this discrepancy.

A radar cross-section at 2.3 km MSL (Fig. 3b) reveals a slightly larger patch of < 10 dBZ reflectivity (compared to the size of the patch at 0.8 km) at the location of the first turn in the approach pattern. Comair-3272 had descended from 11,000 ft (3352 m - all heights MSL) at 2045 UTC and slowed from ~350 knots to ~240 knots before entering the first turn at 2050 UTC (see Table 3a). According to preliminary information from Embraer engineers, the airplane was "clean" until it descended to 7000 feet (~2133 m) MSL, and started to pick up drag at ~204945 UTC, possibly indicating the onset of ice accretion on the aircraft. Comair-3272 reached this altitude when it entered the patch of lower reflectivity at ~204904 UTC, held at 7000 ft until 205113 UTC, then gradually descended as it flew toward the southeast through the low reflectivity patch, reaching an altitude of 4000 ft (1219 m) by 205403 UTC. It was during this period that drag counts were reported to have increased, with the most rapid increase in drag counts indicated between 5500 and 4500 ft (1675 and 1370 m), according to Embraer engineers. Reflectivity values in the path of flight during this period of time were between ~4 and 9 dBZ. Once Comair-3272 descended to altitudes of 7000 ft or less, it flew through an area with reflectivity values of less than 10 dBZ for ~6 ½ minutes (~5 minutes of which the aircraft was picking up drag, according to the preliminary engineering data - *possibly* in icing conditions) before attempting to make a left turn on approach to Detroit at 205426 UTC and 4000 ft (1219 m). During this portion of the flight, the plane was traveling at between approximately 160 and 180 knots in an environment where temperatures were between -6 and -11 C, according to the Detroit balloon borne sounding released at 2300 UTC. Total temperatures calculated for this period were between -3 and -7C.

NW 272 (a DC 9) also descended into the patch of low reflectivity at 7000 ft and made a right turn within it, essentially following the path of Comair-3272, but was about two minutes behind it (see 2050 UTC locations on Fig. 3b; Table 3b). NW 272 flew at similar altitudes at speeds of 150 to 170 knots, and, thus, had similar total temperatures to Comair-3272. The pilot reported that this was "the worst ice (the pilot) had seen all season" with some splashback and described the ice as "extremely heavy to severe" based upon "18 years of operations in the Detroit and Lake Erie areas." The pilot also reported that ice was accreting at a rate of approximately ½ inch of ice per minute, that the plane was flying in solid overcast conditions and that the radar showed little or no returns. When asked to hold altitude, the pilot asked to climb out and did so by making a U-turn at the southeastern end of the low reflectivity patch. Overall, NW 272 appeared to be within the patch of less than 10 dBZ reflectivity at altitudes at or below 7000 ft for more than 8 minutes.

America West (AWE) flight 50 (an Airbus 320) passed over the top of Comair-3272 at ~2045 UTC and was a minute or so ahead of it at 2050 UTC (see Fig. 3b, Table 3c). This aircraft did not descend to 7000 ft until after making the initial turn at 8000 ft, reaching an altitude of 7000 ft at the eastern edge of the low reflectivity patch. This aircraft spent approximately two minutes in areas of less than 10 dBZ at altitudes of 7000 ft or less. The pilot did report moderate rime icing with possible freezing drizzle and light snow. The pilot reported an ice accumulation of approximately l/4 inch and an icing exposure time of 5 to 8 minutes, much of which appears to have occurred at altitudes above 7000 ft and/or in areas of higher reflectivity to the east of the patch. Visible moisture was mentioned, and the pilot also indicated that light and occasionally moderate turbulence was present. Overall, Comair-3272, NW-272 and AWE-50 were all flying in a similar environment, but AWE-50 was exposed to the area of low reflectivity at altitudes of 7000 ft or less for a shorter amount of time.

NW-483 (a Boeing 757) descended into the center of the patch at ~204630 UTC and crossed through to the eastern edge rather quickly (Fig. 4, Table 3d). This aircraft was traveling speeds of roughly 210 to 280 knots through the patch and had total temperatures of between -3 and 0 C. The pilot only reported light snow and no icing on approach to DTW. This aircraft only briefly passed through the patch of reflectivity < 10 dBZ at altitudes of 7000 ft or less, causing a relatively short exposure (~2 minutes) to the environment that existed there. NW-208 (an Airbus 320) essentially crossed over the patch at altitudes of more than 7200 ft between 2038 and 2040 UTC, descending below 7000 ft into reflectivity of ~10 dBZ on the far east side of the patch, missing most of it (Fig. 5, Table 3e). The pilot of that aircraft reported rime icing, with l/2 inch or less accumulation and light snow during descent.

Overall, the differences in exposure time and aircraft speed are likely to account for the wide variety of icing reported by these pilots in interviews following the crash. This is especially true if, indeed, the top of the icing layer was near 7000 ft MSL.

5. Cloud top height and possible shear layers

Examination of data from the DTX radar show that when looking toward the south-southwest (~200 degrees), patchy reflectivity is only evident out to ~55-60 km on the 2.4 degree elevation scan (Fig. 2c), indicating that the height of the highest radar-detectable particles was near 8900 ft MSL, and the pocketed nature of the reflectivity in this region points towards some variability in the height of the tops. Note that this height is not necessarily the same as cloud top, which may he higher. A close look at the radial velocity field on the 2.4 degree scan (Fig. 6) reveals the existence of multiple weak shear layers within the cloud depth, evidenced by slight changes in the azimuthal location of the 0 ms^{-1} radial velocity line with increasing distance from the radar (and thus, height). DTX sounding data (see Table 2a) also indicate the existence of some shear between 5900 and 8770 ft (1800-2675 m), in the upper portion of the layer with relative humidity values in excess of 95%. The next relative humidity value available in the sounding was 83% with a temperature of -16C at 10,700 ft (3250 m). Relative humidity values dropped sharply above this altitude, indicating a lack of cloud there. Infrared data from the GOES-9 satellite indicate cloud top temperature values of approximately -17C over and to the south of Detroit, which roughly matches the cloud top heights inferred from the sounding data at 10,700 ft and -16C. The essentially liquid-saturated values of relative humidity that existed in the DTX sounding between 1700 ft (also the height of cloud base reported by DTW at 2100 UTC to 8800 ft may serve as an indication that this layer was made up of predominantly liquid cloud, while a layer mostly comprised of snow may have existed above this. The 8800 ft height closely matches the approximate height of the radar reflectivity tops to the south-southwest of the Detroit airport. Pilots in the area reported cloud top heights ranging from 5000 to 11,000 ft (except for higher tops of 16,000 ft to the north), and moderate or greater intensity icing, both rime and mixed in type, between 4,000 and 11,000 feet MSL. Some pilots also reported the existence of multiple cloud layers around Detroit.

Overall, the assessment of cloud top height is difficult for this case. It is quite clear, however, that cloud tops were lower to the south of Detroit and that Comair-3272 was flying in a location of transition between deeper, snow clouds to the north and shallower, lightly precipitating or non-precipitating clouds to the south.

6. Radiometer data from Toronto, Ontario

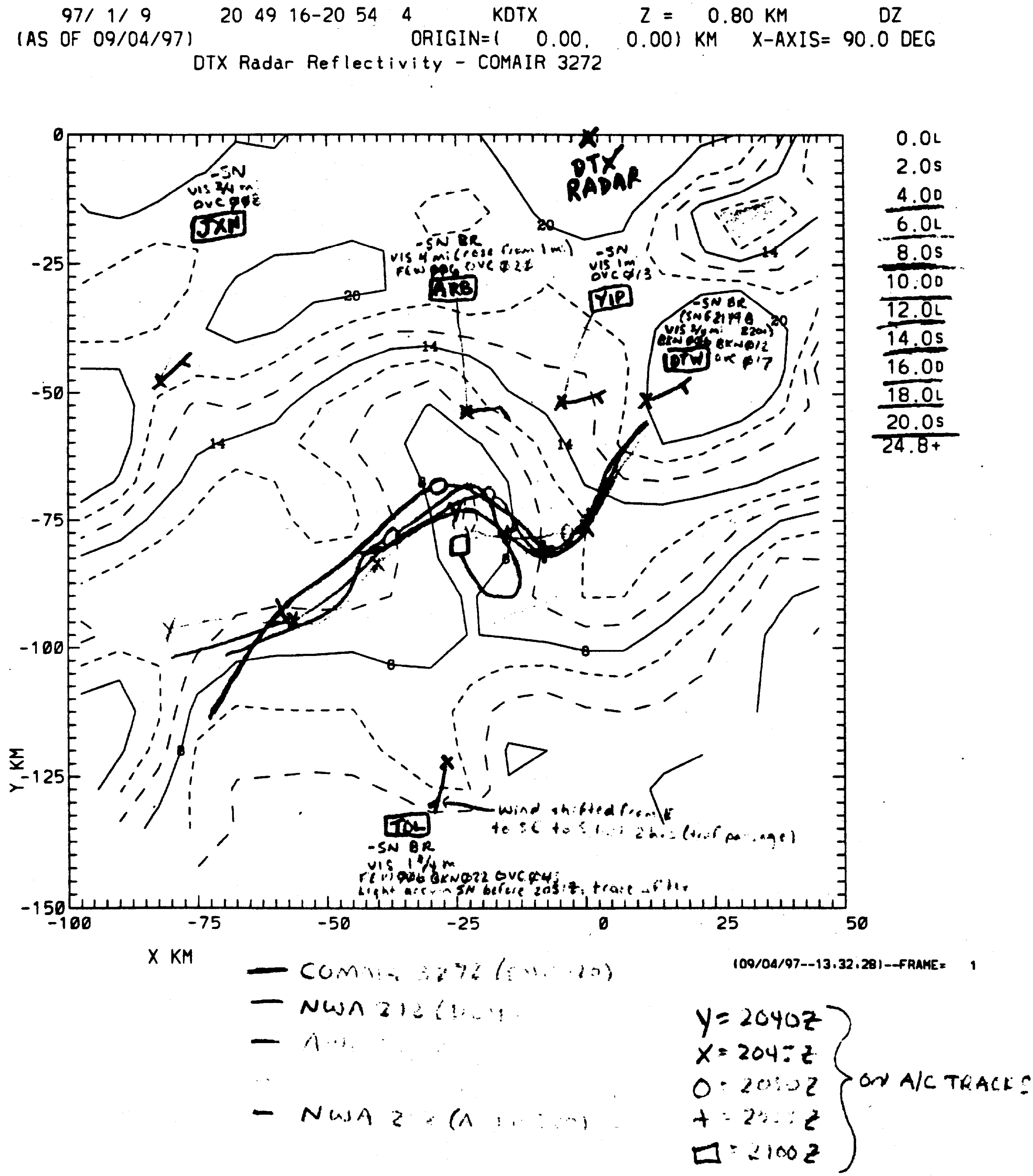
Data from a microwave radiometer located downstream of the crash site at Toronto (43.964 N, 79.574 W) indicated integrated liquid water contents of 0.05 to 0.8 kg/m^2 as the area of relatively warm cloud tops and low radar reflectivity that was over the crash site reached the radiometer between the hours of 2300, 9 January and 0200, 10 January (see Figs 1a-b, 7a-c, 8). Tracking of the radar features was not easily done, but the b ack edge of the reflectivity region was used to roughly approximate the downstream location of the portion of the storm in which the aircraft crashed. Using this method, the back edge of the radar reflectivity appeared to pass the radiometer near 0000 UTC, 10 January, when liquid water contents were near a short-lived minimum. Water content values were as high as 0.8 near 2300 UTC, then gradually dropped to near zero at ~0000 UTC, rose sharply to 0.5 at the 0030 UTC, dropped again to 0.1 by a 0100 UTC, then rose gradually to 0.8 at ~0200 UTC. It is difficult to say which, if any, of these liquid water contents was representative of the water content present at the time and location of the crash, but this range of values is certainly plausible for that environment. Using representative reflectivity values from the Detroit radar and a range of liquid water content values from the Toronto radiometer, one can roughly approximate the range of drop diameters, using a monodisperse distribution of liquid droplets. Assuming an all-liquid cloud with depth of ~2000 m (~6500 ft), integrated liquid water contents of 0.05 to 0.8 kg/m^2 and that the liquid water content was distributed evenly through the depth of the cloud, the average liquid water content would have been between 0.025 and 0.4 g per cubic meter. Using this range of values and representative reflectivity values of 5 dBZ, the expected drop sizes are approximately 200 to 400 microns (see Fig. 9). It is important to note that higher and lower values of LWC and corresponding lower/higher droplet sizes are likely to have existed within portions of the cloud depth, since the liquid water is unlikely to have been evenly distributed through the depth of the cloud.

7. Summary and conclusions

The evidence for the existence of icing conditions along the Comair-3272 flight track is strong and there are several clues present which suggest that freezing drizzle may have also existed there. The possibility that freezing drizzle existed within this cloud is supported by 1) reports of ice pellets and/or graupel in surface observations, 2) a report of possible freezing drizzle by the pilot of America West 50, 3) the report of extremely heavy to severe icing with some splash back and fast accumulation rates (1/2 inch per minute) by the pilot of NW 272, and 4) the roughly calculated drop sizes based upon reflectivity data from the DTX radar and the Toronto radiometer.

8. Acknowledgments

Thanks to J. Walter Strapp of the Atmospheric Environment Service of Canada for supplying the Toronto radiometer data, and to Greg Thompson for his help with the analysis of the GOES-9 satellite data.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0.0L
2.0S
4.0D
6.0L
8.0S
10.0D
12.0L
14.0S
16.0D
18.0L
20.0S
24.8+
DTX RADAR
JXN
ARB
YIP
DTW
TDL
Y KM
X KM
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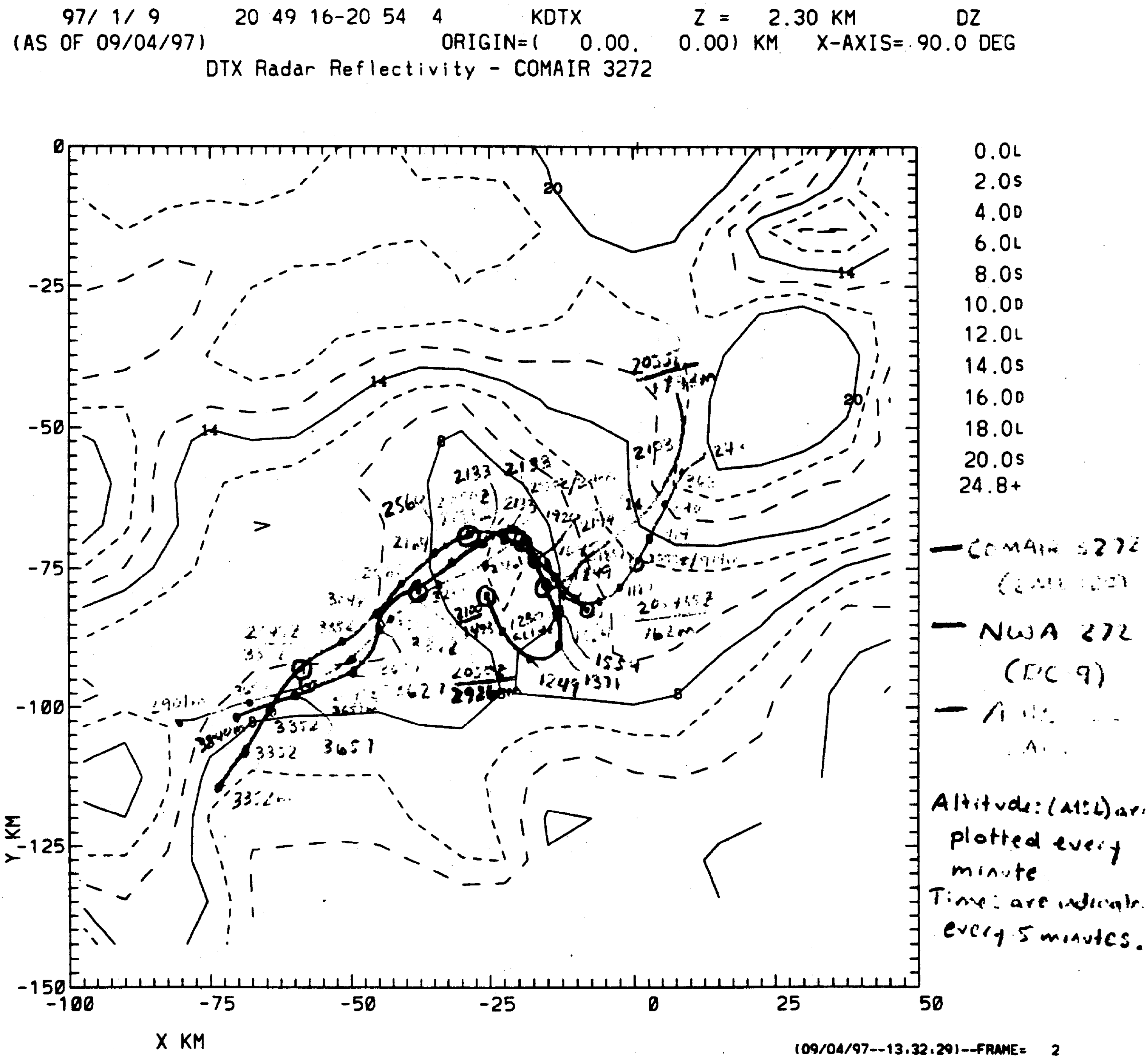
□ = 2100Z
ON A/C TRACKS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(AS OF 09/04/97) ORIGIN=(0.00, 0.00) KM X-AXIS= 90.0 DEG
DTX Radar Reflectivity - COMAIR 3272
0.0L
2.0S
4.0D
6.0L
8.0S
10.0D
12.0L
14.0S
16.0D
18.0L
20.0S
24.8+
Y KM
X KM
(09/04/97--13.32.29)--FRAME= 2
NWA 272
(DC 9)
Altitudes (MSL) are plotted every minute
Times are indicated every 5 minutes.

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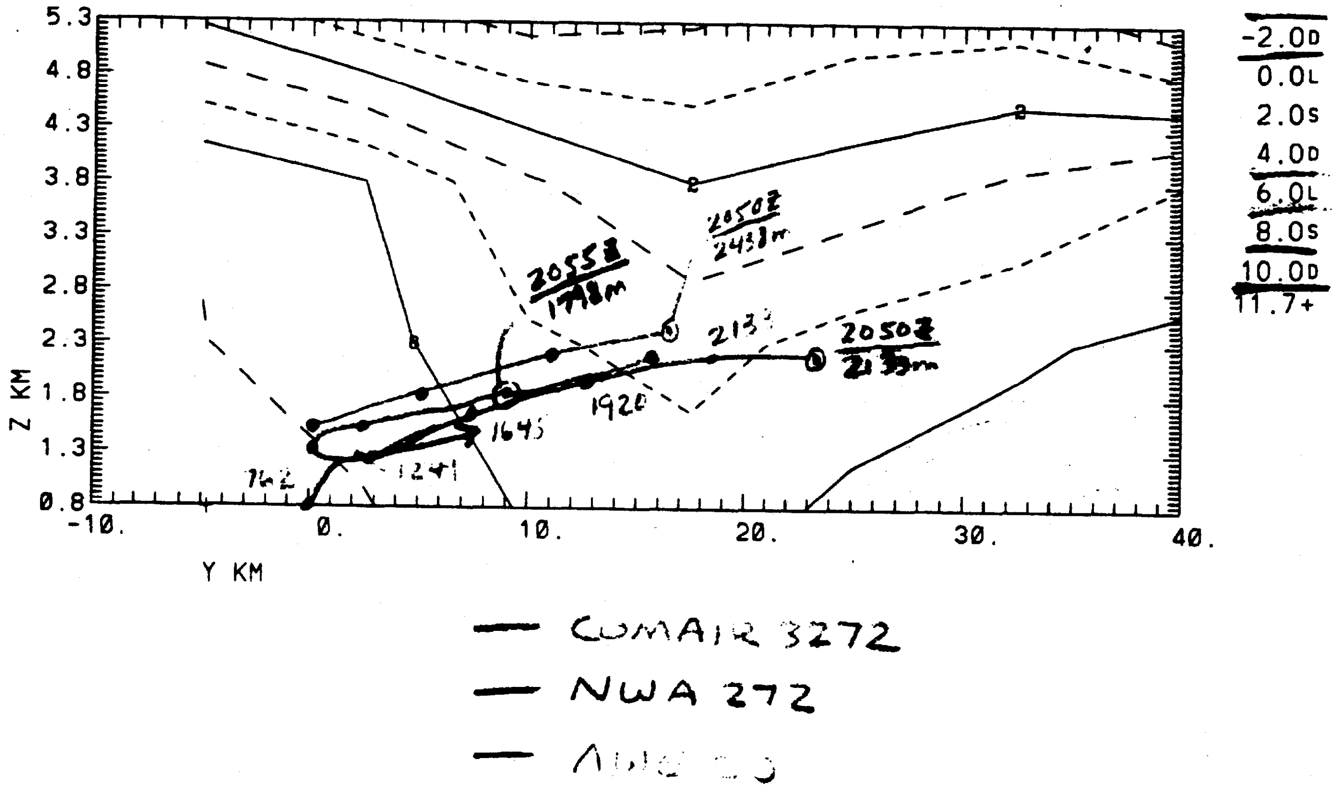
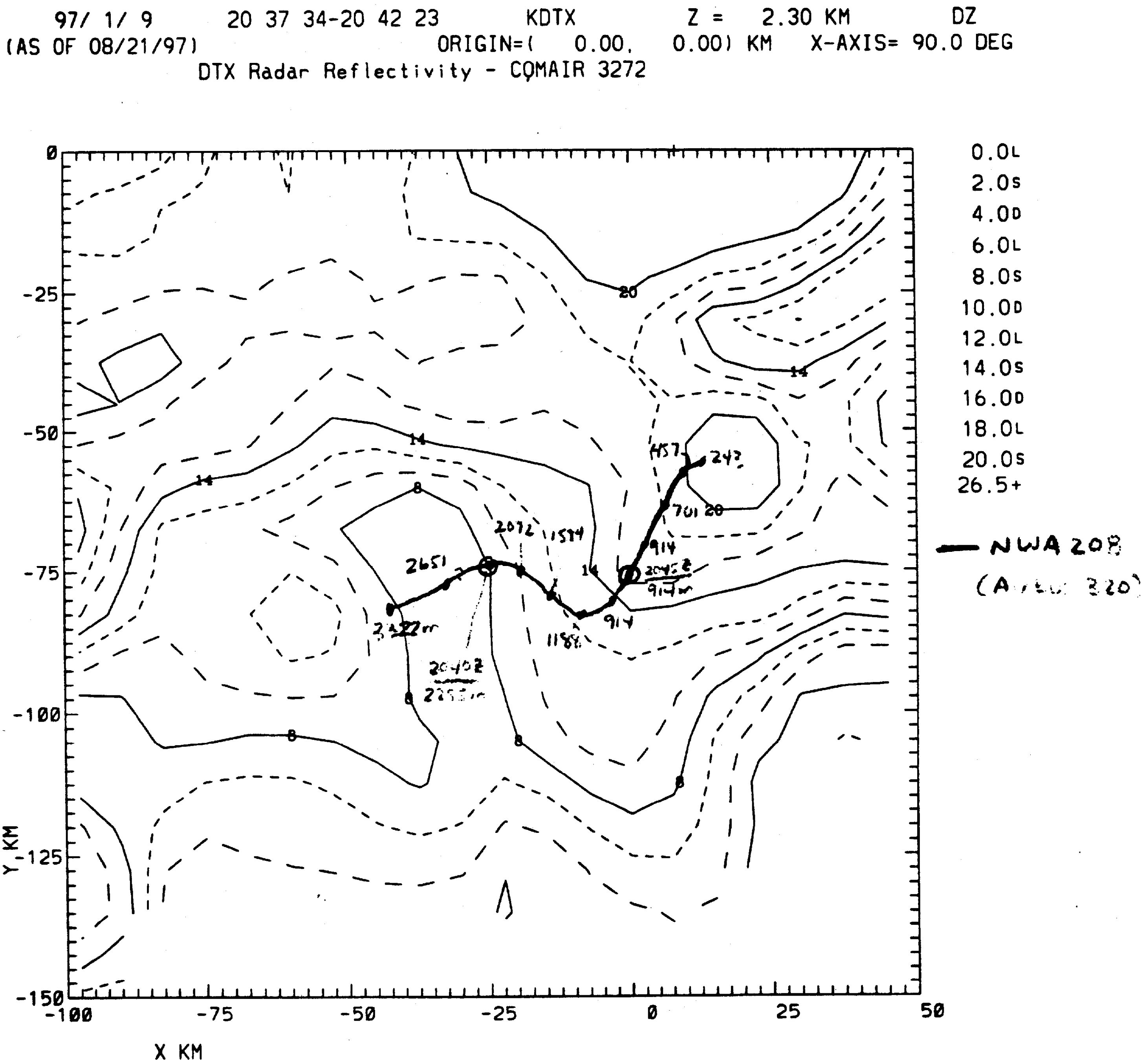
DTX Radar Reflectivity - COMAIR 3272

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DTX Radar Reflectivity - COMAIR 3272
0.0L
2.0S
4.0D
6.0L
8.0S
10.0D
12.0L
14.0S
16.0D
18.0L
20.0S
26.5+
NWA 208
Y KM
X KM
0
-25
-50
-75
-100
-125
-150
-100
-75
-50
-25
0
25
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