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# An Assessment of Thunderstorm Penetrations and Deviations by Commercial Aircraft in the Terminal Area

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16. Abstract

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The report indicates that it is possible to train a statistical classifier that characterizes the probability that pilots will penetrate or deviate around airspace occupied by thunderstorms. The analysis outlines several desirable characteristics of a probability-of-deviation classifier. The classifiers trained and tested in this study were able to correctly classify more than 80 percent of the storm cell encounters in an independent data set. Those classifiers could be used as a starting point for evaluating the utility of probability-of-deviation maps in automated decision aid tools-particularly for those regions of the TRACON more than 20-30 km from the airport.

The analysis does not find any correlation between the weather variables and the pilots' penetration/deviation behavior near the destination airports. The vast majority of encounters near the airport in this study resulted in penetrations. Pilots penetrated storms with precipitation intensities of NWS level 3, 4, and 5. Finally, arriving aircraft in this data set were more likely to penetrate storms when they were following another aircraft, more than 15 minutes behind where they ought to be based on the nominal flying time scheduled for the trip, or when they were flying after dark.

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## ABSTRACT

This analysis investigates which weather variables are correlated with arriving pilots' convective cell penetration/deviation behavior in the DFW terminal airspace. Far from the airport, the pilots' behavior is well correlated with a small number of weather variables. Three-dimensional data yielded the best correlation but two-dimensional storm intensity variables were also strongly correlated with the pilots' behavior.

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## EXECUTIVE SUMMARY

This study models the penetration and deviation behavior of aircraft flying near convective weather in the Dallas-Fort Worth airspace as a function of weather characteristics. The objective is to determine which variables are correlated with the penetration/deviation decision. The research is intended to be helpful to the designers of air traffic automation systems and air traffic management decision support tools by quantitatively characterizing the propensity of pilots to penetrate or deviate around convective weather. Likewise, the research is intended to be helpful to convective weather product designers by determining which variables need to be predicted if the overall objective is to predict the likelihood of aircraft deviations and penetrations when there is convective weather in the terminal area.

Slightly more than 60 hours of convective weather and flight data were examined for this study. Flight data were studied for arriving aircraft. During that time, there were nearly 2000 aircraft encounters with weather. Roughly one third of the encounters resulted in deviations and two-thirds resulted in penetrations. Weather and flight variables were collected for each encounter and the data were analyzed using a pattern classification software package. Several pattern classifiers were trained on a portion of the data and tested on the remaining data.

The data show very little variation in pilots' behavior near the destination airport; nearly all of the encounters within 20-30 km of the airport resulted in penetrations. There were not enough deviation observations near the airport to correlate the deviation behavior with any of the weather variables. Further work will be necessary to characterize pilots' deviation behavior near the airport and penetrations with apparent subsequent regret. Pilots penetrated some stronger weather near the airport, which underscores the importance of highly capable wind shear detection and prediction systems.

Farther away from the airport, several weather variables were well correlated with the pilots penetration/deviation behavior. A neural net classifier yielded the best classification performance; it correctly predicted the penetration/deviation behavior of more than 80 percent of the encounters in the testing data set. The classifier used only four variables: weather intensity, percent of the region covered in light precipitation, percent of the region covered in heavy precipitation, and range of the encounter from the airport.

In addition, arriving aircraft in this data set were more likely to penetrate convective weather when they were:

- Near the destination airport rather than farther away,
- Following another aircraft,
- More than 15 minutes behind where they ought to be, based on the nominal flying time scheduled for the trip, or
- Flying after dark.

Finally, no statistically significant differences were found in different airlines' propensity to penetrate weather.

## ACKNOWLEDGMENTS

This research was sponsored by the Center-TRACON Automation System (CTAS) activity within NASA's Terminal Area Productivity (TAP) program.

The flight track data used in this study were collected using software that was written at NASA Ames in the development of the CTAS. The hardware used to collect the flight track data was developed, installed, and maintained by Phil Zinno at the FAA Technical Center. The authors thank both NASA and the FAA Technical Center for their assistance in the acquisition of the flight track data.

The authors benefited greatly from conversations with Drs. James Evans, Robert Boldi, and Richard Lippmann of MIT Lincoln Laboratory (MIT/LL) in the formative stages of the project and with Drs. Earle Williams (MIT/LL) and R. John Hansman of MIT in the analysis phase of the project.

The authors are deeply indebted to the meticulous data entry and analysis efforts of Elizabeth Bouchard, Cynthia Meuse, Timothy Rotz, Patricia Selfridge, and Wayne Upham.

The appendix of this report contains descriptions of the nine weather days that were examined in this study. Those descriptions were taken from the daily operations reports issued by the staff of the MIT Lincoln Laboratory Dallas-Fort Worth Integrated Terminal Weather System field site. The authors are grateful to Timothy Rotz and Kim Theriault for their contributions to those reports. The authors are also grateful for access to the DFW TRACON Traffic Management logs, which also appear in the appendix.

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# 1 INTRODUCTION

During thunderstorm periods, terminal air traffic planners[1] make a number of important decisions. They decide when to close and re-open arrival fixes, departure fixes, and runways; they anticipate and execute changes in runway configuration; they negotiate routing and flow rate decisions with Air Route Traffic Control Center (ARTCC) traffic managers; and they set the airport acceptance rate. In making each of these decisions, the traffic planners look at a weather radar display and make an educated guess at the following questions:

- What will the weather be like in the airspace and time period in question?
- Will the pilots be able and willing to fly through the weather?

There are many practical corollaries to these two fundamental questions: When will aircraft start to deviate from the standard routes? How long will a particular route be viable? When will the routes become viable again? Will all the pilots in a stream of traffic accept the same route or will some ask for deviations from the primary route? Each of these corollaries may be reduced to the two fundamental questions.

The same questions will be important for advanced terminal automation systems. One important element of air traffic automation systems such as the Center-TRACON Automation System (CTAS) and the User Request Evaluation Tool (URET) is the calculation of candidate trajectories for each aircraft for the period of automation control. To make this calculation, the automation software must know which routes will be usable during the control period, or it must be able to attribute a cost to the use of alternative routes.

The first of the two fundamental questions is being addressed by the convective weather Product Development Team (PDT) of the FAA's Aviation Weather Research program. (Wolfson, 1997; Wolfson, 1999; Hallowell, 1999; Forman, 1999; Evans, 1997) The second fundamental question is the subject of the work reported here.

## 1.1 Background

Several researchers have recognized that the second fundamental question is important. At least two studies have suggested that routing algorithms should employ cost functions or weighted regions to compare the relative merits of alternative routes. (Hunter, 1995; Krozel, 1997) For purposes of simplicity, others have used strict radar reflectivity thresholds to split the airspace into regions where pilots "will" and "will not" fly. (Dixon, 1993) Finally, some researchers have interviewed pilots to understand their stated preferences for route selection in the presence of weather. (Weidner, 1997) To our knowledge, the work reported here is the first attempt to use a large data set to quantitatively characterize pilots' penetration/deviation behavior as a function of weather variables.

The traditional air traffic control answer to the second question is a widely quoted rule-of-thumb which says that pilots generally do not penetrate precipitation that is NWS VIP level 3 (i.e., 41 dBZ) or higher. That is not to say that air traffic controllers always vector aircraft around level 3+ cells but rather that they begin to anticipate pilot requests for deviations when the weather approaches level 3. Until recently the only weather radar product available to terminal traffic planners was the six level product from the Airport Surveillance Radar (ASR). New

[1] Although this study has focused on terminal route planning, the basic issues are equally applicable to en route airspace and to airline flight dispatch, including Collaborative Decision Making (CDM) systems.

weather radars and sensors have come on-line in recent years that are capable of generating a number of new weather products.

The goal of this research is to analyze the six-level ASR data along with variables from the newer weather sensors and determine which combination of products is best correlated with pilots' storm cell penetration and deviation behavior.

The study's approach is as follows:

1. Measure arriving aircraft positions and weather data in the DFW Terminal Radar Approach Control (TRACON) for some thunderstorm days.
2. Extract the weather data from parts of storms that the planes penetrate.
3. Extract the weather data from parts of storms that clearly cause aircraft to deviate.
4. Employ a pattern classification software package to determine which combinations of weather variables are correlated with the pilots penetration/deviation behavior.
5. Split the data set into training and testing subsets. Train and test various candidate classifiers to assess their suitability for generating a map of pilots' probability-of-deviation around weather.
6. Test several hypotheses about various flight-related variables and the penetration/deviation decision.

Chapter 2 describes the weather variables that were employed in the study and the sensors from which the variables were derived. Chapter 3 is a description of the flight track and delay data employed in this study. Chapter 4 describes how the flight track and weather data were used to identify aircraft encounters with storm cells, how weather data were extracted from relevant Cartesian maps, and how the data set was reduced to manageable proportions. A brief description of the storm cell encounter data set is included in Chapter 5. Chapter 6 describes the statistical analysis of the data set, the method of determining which variables were correlated with pilots' behavior, the performance of several candidate statistical classifiers, and the results of testing several hypotheses regarding flight variables. Chapter 7 enumerates the conclusions of the study and Chapter 8 suggests several logical follow-on studies.

## 2 WEATHER SENSORS AND VARIABLES

Weather data were obtained for nine thunderstorm days in the spring and summer of 1997 from sensors associated with MIT Lincoln Laboratory's Integrated Terminal Weather System (ITWS) testbed at the Dallas-Fort Worth International Airport. The weather sensors include four fan-beam Airport Surveillance Radars (ASRs), two pencil-beam Terminal Doppler Weather Radars (TDWRs), and one pencil-beam Next Generation Weather Radar (NEXRAD) as well as the National Lightning Detection Network (NLDN). Figure 1 shows the locations of the weather radars. Table 1 lists the radar parameters. Figure 2 shows a cross section of a pencil-beam radar's volume coverage pattern and illustrates the vertical extent of the data used in the study.

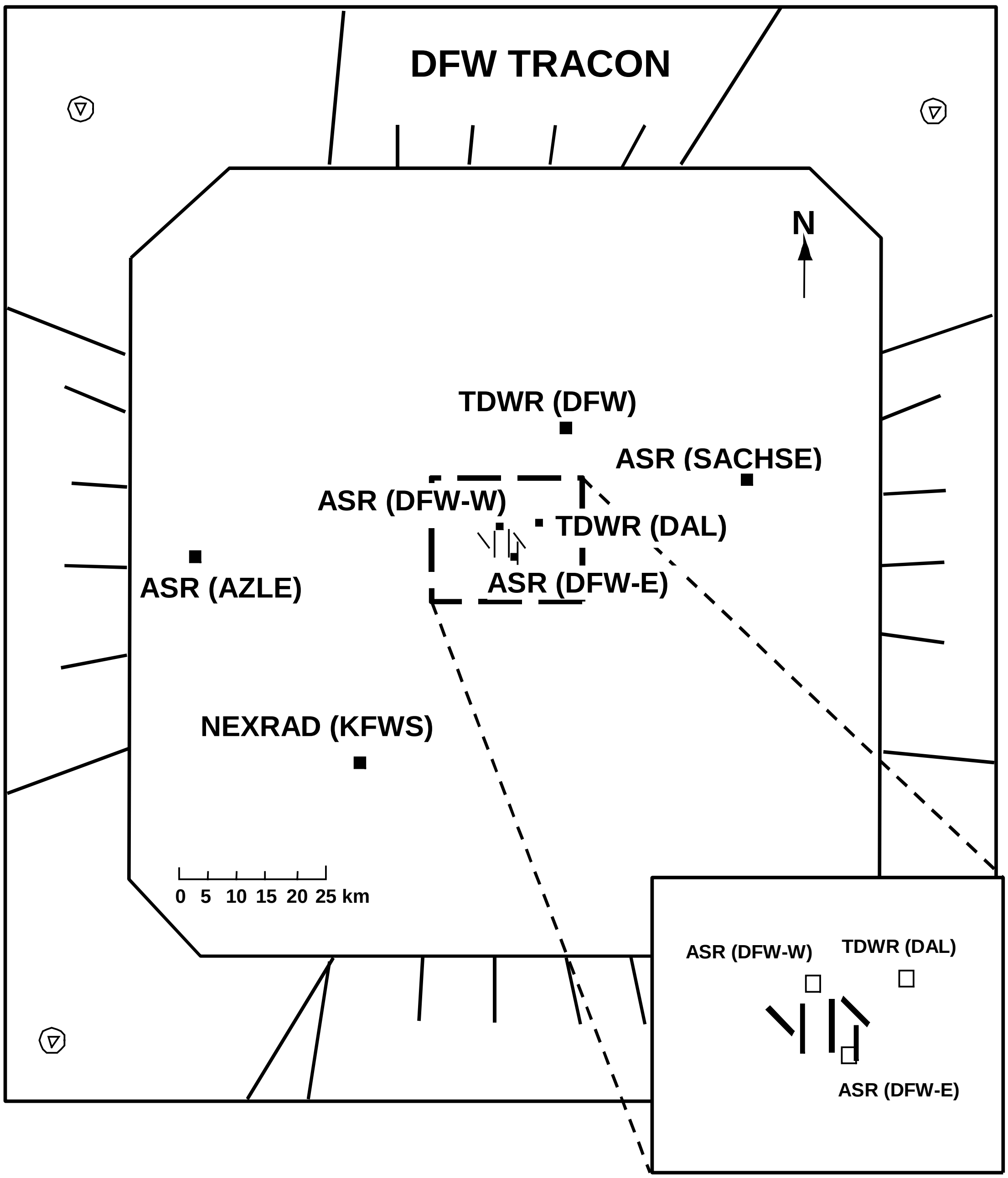
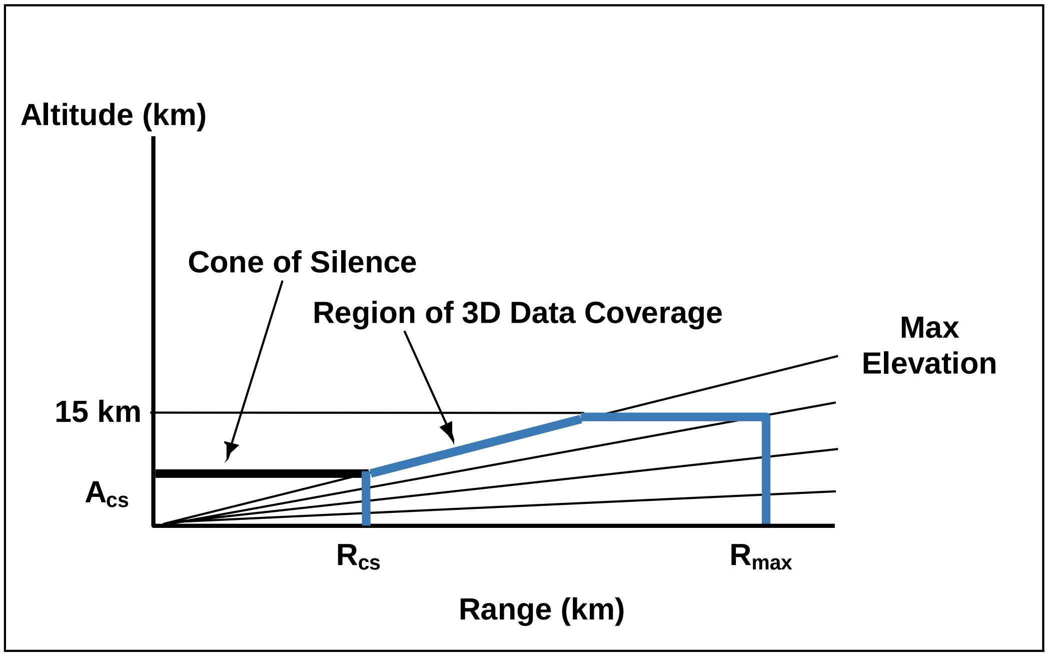



*Figure 1. DFW Terminal Radar Approach Control (TRACON) airspace and weather sensor locations.*




| | $R_{cs}$ (km) | $R_{max}$ (km) | $A_{cs}$ (km) | Max Elevation |
|---|---|---|---|---|
| NEXRAD (weather mode) | 16 | 130 | 6 | 19.5° |
| TDWR (DFW) (hazardous mode) | 10 | 60 | 6 | 29.7° |
| TDWR (DAL) (monitor mode) | 8 | 60 | 6 | 39.7° |

*Figure 2. A vertical cross-section of the region of 3D radar coverage for the TDWRs and NEXRAD. $R_{cs}$ is the range at which $A_{cs}$ is equal to approximately 6 km. $R_{cs}$ is a function of the elevation angle of the highest tilt in the scan strategy (Max Elevation). $R_{max}$ is the maximum range for which data are used. This range is a function of the scan strategy (i.e., the number of tilts and the gaps between tilts) and was set so that reasonable inter-tilt interpolation of the data could be performed. Max Elevation is the tilt with the highest elevation angle in the "hazardous" or "weather" mode. Weather data were gridded to a maximum altitude of 15 km.*

**Table 1.**
**Radar Characteristics for Each of the Radars Used in the Study. Note that "max range" is the maximum range for which data were used in the study and not necessarily the maximum range for which data are collected by the radar.**

| RADAR | RADAR TYPE | BAND | VOLUME SCAN UPDATE RATE | BEAMWIDTH (EL/AZ) | RANGE GATE SIZE | MAX RANGE |
|---|---|---|---|---|---|---|
| TDWR | PENCIL-BEAM | C-BAND | 2.5 MIN HAZARDOUS 5.0 MIN MONITOR | 0.5°/0.5° | 150 m | 60 km |
| ASR | FAN-BEAM | S-BAND | 30 SEC | 4.8°/1.4° | 116 m | 111 m |
| NEXRAD | PENCIL-BEAM | S-BAND | 6.0 MIN | 1°/1° | 1000 m | 130 km |

Radar data were converted from their original polar format to Cartesian grids. The pencil-beam reflectivity data from the TDWRs and NEXRAD were mapped to a 3D grid and the ASR precipitation product was mapped to a 2D grid. The horizontal and vertical grid resolution used in this study is 1 km. Several two-dimensional products were computed for each 3D column of radar reflectivity in the pencil-beam data.

The list of meteorological sensors and their products includes:

<u>Airport Surveillance Radar (ASR-9, hereafter referred to as ASR)</u>

- Precipitation (NWS six-level VIP scale)
- Percent of each quadrant of the TRACON covered in level 2 or higher precipitation
- Percent of each quadrant of the TRACON covered in level 4 or higher precipitation
- Percent of the entire TRACON covered in level 2 or higher precipitation
- Percent of the entire TRACON covered in level 4 or higher precipitation

<u>Next Generation Weather Radar (NEXRAD)</u>

- Probability of severe hail
- Mesocyclone detection
- Tornado detection
- Radar reflectivity (DZ)

The following 2D products were calculated for each vertical column of reflectivity:

⇒ maximum reflectivity (MAXVAL)

⇒ height of the maximum reflectivity

⇒ height of the center of mass of the reflectivity

⇒ highest altitude of significant radar returns (ECHO TOP)

⇒ lowest altitude of significant radar returns (ECHO BOTTOM)

⇒ vertical extent of region with significant radar returns

⇒ vertically integrated liquid water content (VIL)

<u>Terminal Doppler Weather Radar (TDWR)</u>

- Microburst detection
- Gust Front Detection
- Radar reflectivity (DZ)

The following 2D products were calculated for each vertical column of reflectivity:

⇒ Maximum reflectivity (MAXVAL)

⇒ Height of the maximum reflectivity

⇒ Height of the center of mass of the reflectivity

⇒ Highest altitude of significant radar returns (ECHO TOP)

⇒ Lowest altitude of significant radar returns (ECHO BOTTOM)

⇒ Vertical extent of region with significant radar returns

⇒ Vertically integrated liquid water content (VIL)

<u>National Lightning Detection Network (NLDN)</u>

- Flash rate of cloud-to-ground lightning strikes

The following sections describe the sensors and variables in detail.

## 2.1 Airport Surveillance Radars

### <u>2.1.1 Radar Locations</u>

There are four ASRs inside the DFW TRACON. One is located 20 miles west of the airport (Azle), one is 20 miles east of the airport (Sachse), and two are on the airport (DFW-E and DFW-W). The ITWS precipitation product mosaics data from the Azle, Sachse, and DFW-E radars. DFW-W is essentially co-located with DFW-E and therefore would not add any new information to the mosaic. DFW-W serves as a “hot spare” for DFW-E. See Figure 1.

### <u>2.1.2 Scan Strategy</u>

The ASR is a dual fan-beam radar with a rapid scan rate of 12.5 RPM. The reflectivity data are spatially and temporally filtered to yield a precipitation product approximately every 30 seconds.

### <u>2.1.3 Precipitation Product</u>

ASR precipitation data are quantized according to the six levels used by National Weather Service. See Figure 3. The precipitation data from the three radars are mapped onto 2D grids and mosaicked together (see Section 2.1.5 below) into one final grid which covers the entire TRACON region. The data are also edited to remove any anomalous propagation echoes. (see Section 2.1.4 below). The mosaicked 2D precipitation product was used in this study to determine the intensity of the rain at the 2D location of each aircraft. The study also examined several weather coverage products which were derived from the 2D precipitation product. (See Section 2.1.6)

### <u>2.1.4 Removal of False Echoes</u>

ASRs are subject to anomalous propagation (AP) or false echoes when there is a layer of cool air near the surface of the earth (Battan, 1973). TDWR and NEXRAD are pencil-beam radars and are much less likely to show false echoes. Therefore, before mosaicking the ASR data, the ITWS performs a process known as “AP-editing”—it removes false echoes by comparing the ASR data with the data from the TDWRs and NEXRAD. ASR echoes that are not substantiated by one or more pencil-beam radars are removed from the data before the data are mosaicked. These data are referred to as “AP-edited precipitation.”

### <u>2.1.5 Mosaicking Data from Three Radars</u>

Figure 4 shows the coverage region of each of the ASR radars used in the ITWS precipitation product. The westernmost crescent of airspace covered by the radars is covered only by the Azle radar. Moving eastward, there is a crescent-shaped region that is covered by both Azle and DFW-E. Moving farther eastward, there is a football-shaped region covering most of the TRACON that is observed by all three ASRs. East of the football there is another crescent covered by both DFW-E and Sachse. The easternmost crescent is viewed only by the Sachse radar. In regions of single-radar coverage, the mosaicked ITWS precipitation product is simply the AP-edited precipitation product from the single radar. In areas of dual-radar coverage, if the two AP-edited precipitation products differ at an x,y location, then the mosaic process chooses the higher of the two values. In the region of triple-radar coverage, the mosaic process uses the median precipitation value.

The median filter that is used in the region of triple-radar coverage serves as a final data quality measure, often removing small areas of AP that may have "broken through" the AP-editing process. The combination of the AP-editing process and the median filter in the mosaic process yields a high-quality precipitation product over the majority of the TRACON. If the study were performed using data that were not AP-edited, the results would be biased by apparent weather penetrations that were in fact penetrations of AP echoes.

| Reflectivity | NWS Level | Intensity Code | Possible Turbulence | VIL ($kg/m^2$) | Hail | Rainfall (in/hr) |
|---|---|---|---|---|---|---|
| 57 dBZ | LEVEL 6 | Extreme | Severe | $\geq$ 32.0 | Large | $\geq$ 7.1 |
| 50 dBZ | LEVEL 5 | Intensity | Severe | 12.0 - 32.0 | Likely | 4.5 - 7.1 |
| 46 dBZ | LEVEL 4 | Very Strong | Severe | 6.9 - 12.0 | ---- | 2.2 - 4.5 |
| 41 dBZ | LEVEL 3 | Strong | Severe | 3.5 - 6.9 | ---- | 1.1 - 2.2 |
| 30 dBZ | LEVEL 2 | Moderate | Light / Moderate | 0.8 - 3.5 | ---- | 0.2 - 1.1 |
| 0 dBZ | LEVEL 1 | Weak | Light / Moderate | 0.1 - 0.8 | ---- | < 0.2 |

*Figure 3. Weather levels in dBZ, NWS (VIP) level, and VIL ranges. The weather hazards listed with each weather level are general statements about the possibility that those hazards might be associated with weather of each intensity level. No assumptions were made in this study regarding the presence of those hazards.*

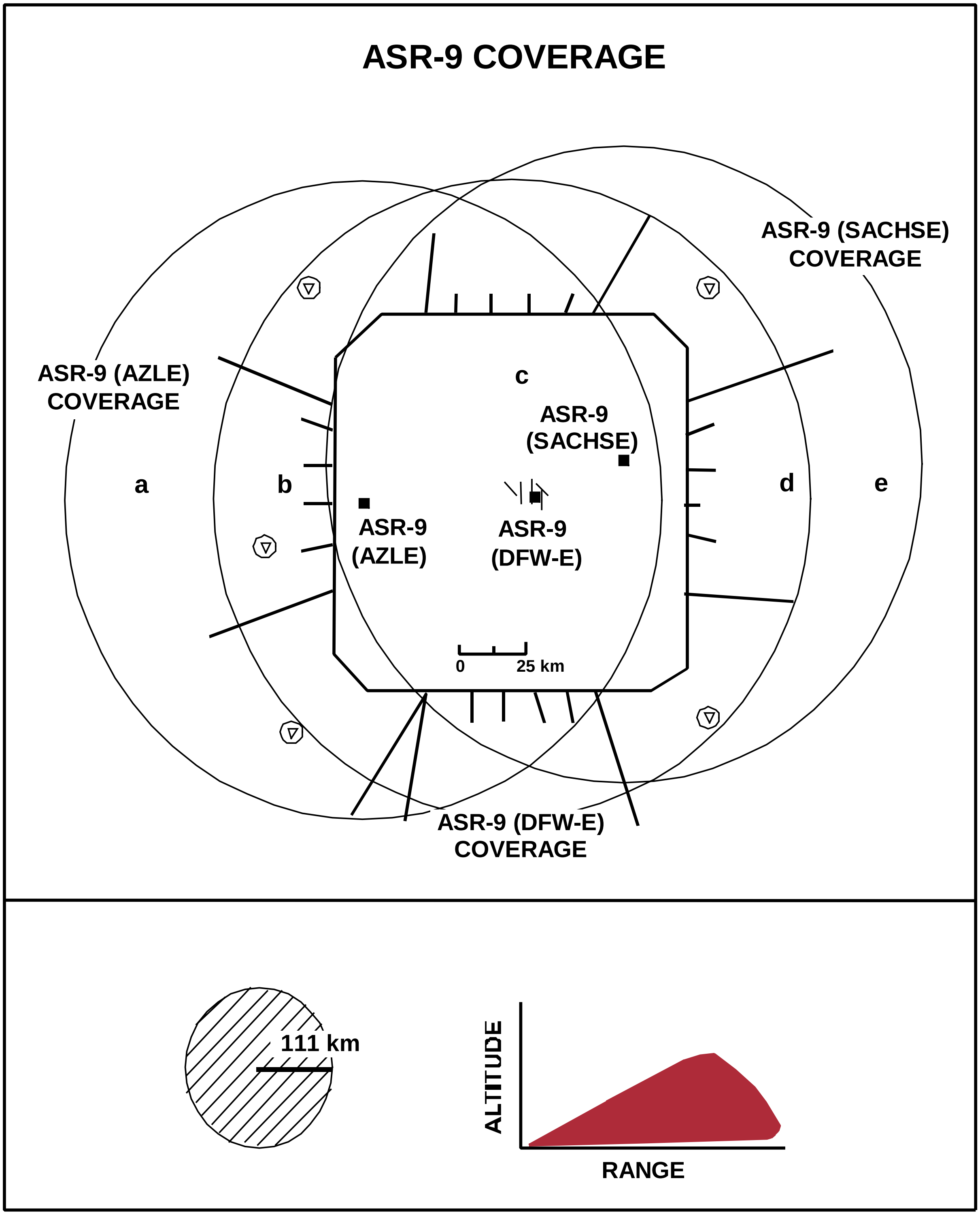



*Figure 4. Location and coverage regions for the three ASR-9 radars used in the DFW ITWS precipitation-with-AP-removed product. In areas where data from two radars overlap, the higher value is used, and in areas where data from three radars overlap, the median value is used. Regions (a) and (e) have single ASR-9 coverage. Regions (b) and (d) have dual coverage, and region (c) has triple coverage. The lower Figure shows a plan view of the scanning range and a vertical cross section of the fan beam coverage of each of the ASR-9 radars.*

#### 2.1.6 Weather Coverage Products

Several products were created from the ASR precipitation maps to serve as proxy variables for the probability that there was a storm-free approach route available to each aircraft at the time of its storm cell encounter. The ASR precipitation product was used to compute the percentage of a particular region covered in at least light (level 2+) precipitation and the percentage of the same region covered in heavy precipitation (level 4+). The products are called "weather coverage" products and they were created for each of the four quadrants of the TRACON and for the entire TRACON itself every 30 seconds (each ASR update). The four quadrants are defined by north-south and east-west lines that intersect at the DFW airport reference point (ARP). See Figure 5. Most aircraft spend a majority of the flight from an arrival cornerpost to a runway in one of the four quadrants. The following is a list of the 10 weather coverage products:

1. NW_Quad_Low  percent of level 2 and higher precipitation in the NW quadrant
2. NE_Quad_Low  percent of level 2 and higher precipitation in the NE quadrant
3. SW_Quad_Low  percent of level 2 and higher precipitation in the SW quadrant
4. SE_Quad_Low  percent of level 2 and higher precipitation in the SE quadrant
5. NW_Quad_High  percent of level 4 and higher precipitation in the NW quadrant
6. NE_Quad_High  percent of level 4 and higher precipitation in the NE quadrant
7. SW_Quad_High  percent of level 4 and higher precipitation in the SW quadrant
8. SE_Quad_High  percent of level 4 and higher precipitation in the SE quadrant
9. TRACON_Low  percent of level 2 and higher precipitation in the TRACON
10. TRACON_High  percent of level 4 and higher precipitation in the TRACON

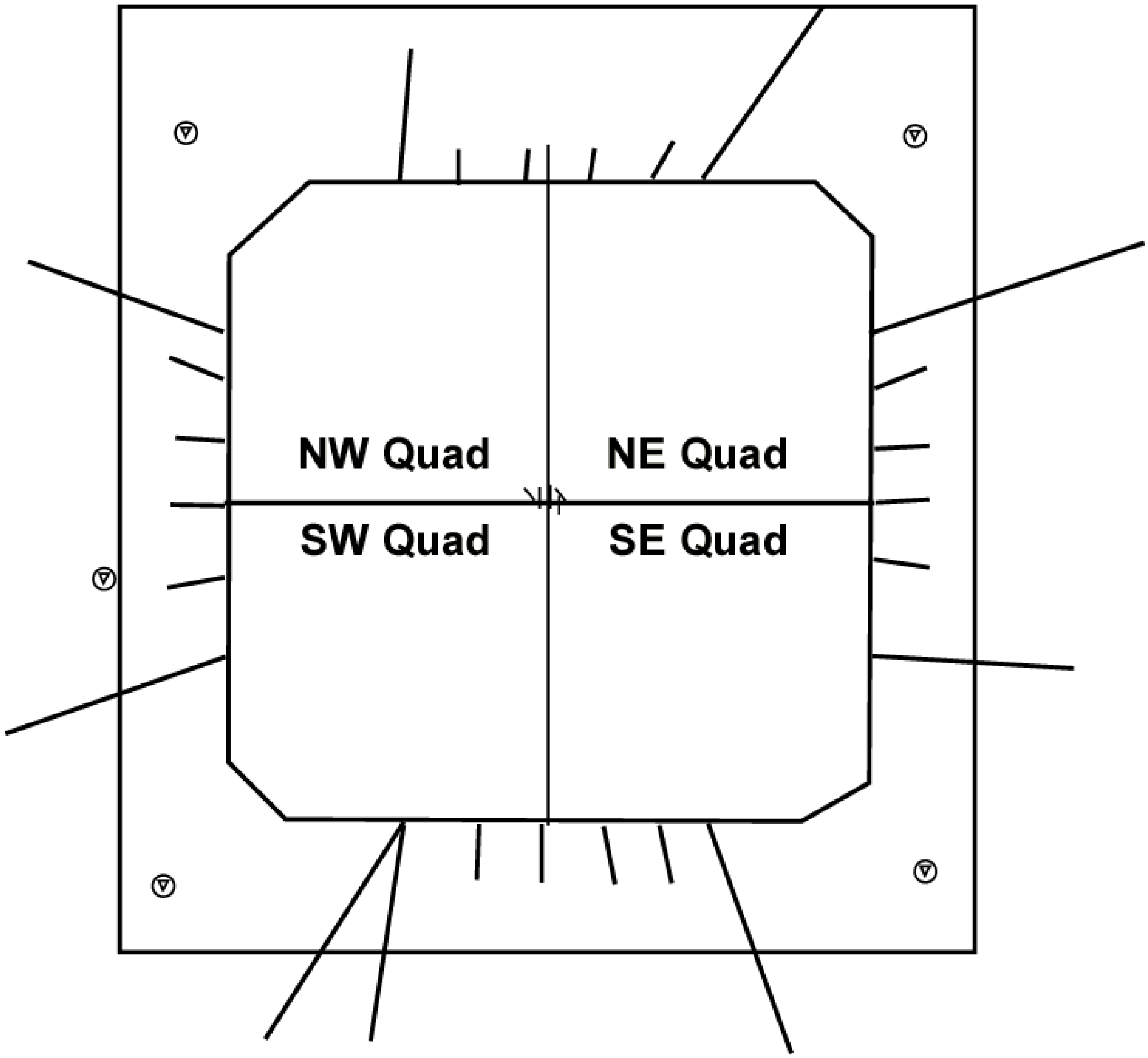



*Figure 5. DFW TRACON divided into quadrants.*

## 2.2 Next Generation Weather Radar (NEXRAD)

### 2.2.1 Radar Location

The KFWS NEXRAD is located slightly south of the city of Forth Worth and approximately 45 km southwest of the DFW airport. Figure 6 shows the region in which NEXRAD products are computed for the purposes of this study.

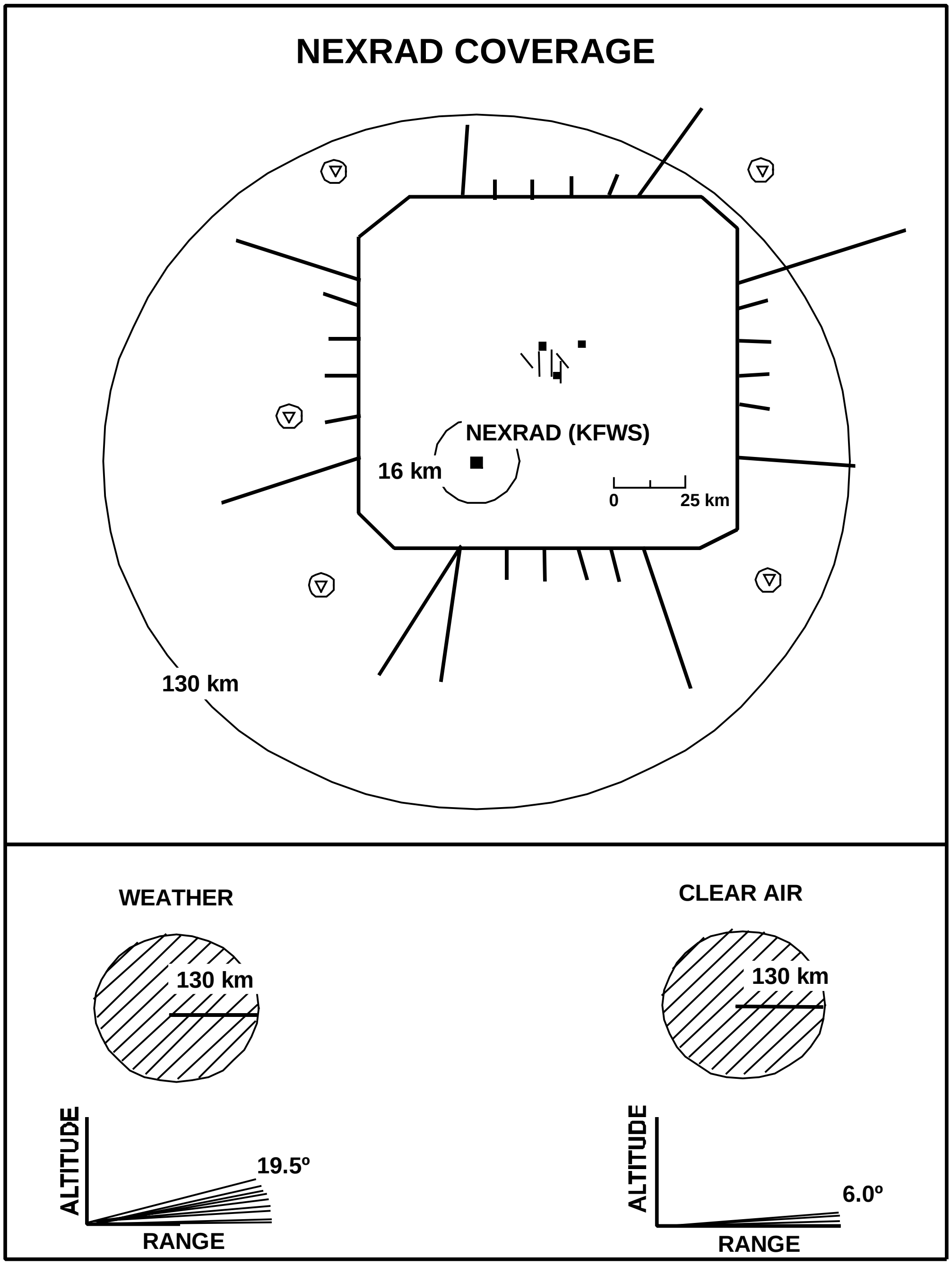



*Figure 6. KFWS NEXRAD location and coverage region. In this study, reflectivity data were used for the regions between 16 km and 130 km from the radar. Data closer than 16 km were not used because the data in that region do not extend to an altitude of at least 6 km. The lower Figure shows a plan view of the scanning range and a vertical cross section of the scan strategy for both "weather" and "clear-air" modes.*

### 2.2.2 Scan Strategy

The NEXRAD usually operates in one of two modes. In clear-air mode, the radar scans up to an elevation of 6.0 degrees and takes approximately 11 minutes to perform a full volume scan. In storm or weather mode, the radar scans up to an elevation of 19.5 degrees and takes approximately six minutes to perform a complete volume scan.

### 2.2.3 Reflectivity-Based Products

The raw radar reflectivity product consists of several scans or “tilts,” each at a different elevation angle. These tilts were mapped into a 3D Cartesian space and interpolated to fill the regions between the tilts. The full 3D radar reflectivity product covers a region extending out 130 km from the NEXRAD and to an altitude of 15 km. The 3D reflectivity product was used in this study to determine the intensity of the rain at the 3D location of each aircraft. The study also derived seven 2D products from the 3D reflectivity product. See Figure 7.

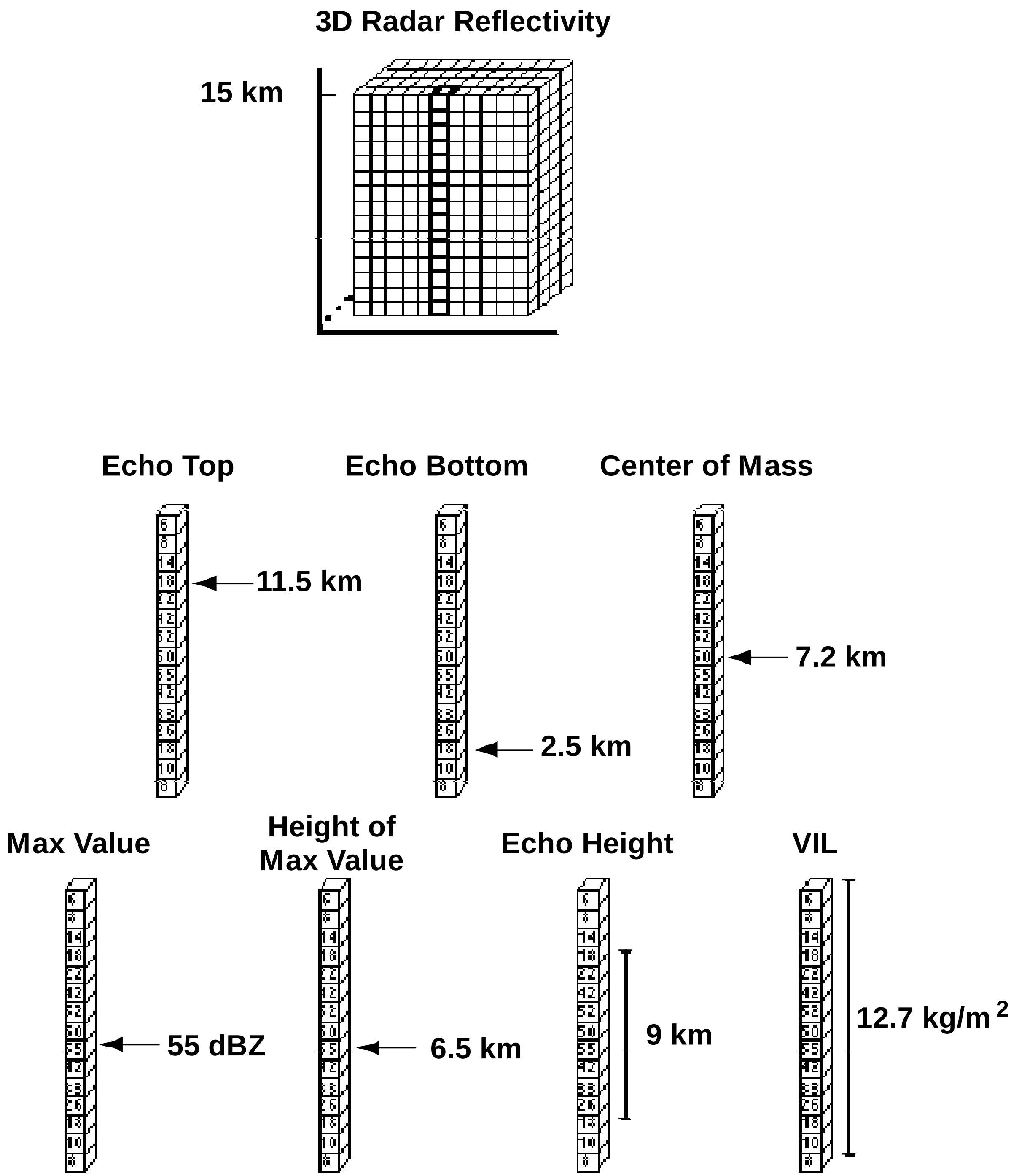



*Figure 7. Reflectivity products derived from pencil-beam radar reflectivity.*

Each of the following seven products describes one characteristic of the column of precipitation at each x,y location.

- Echo Top—Altitude of the highest bin with a reflectivity value > 18 dBZ
- Echo Bottom—Altitude of the lowest bin with a reflectivity value > 18 dBZ
- Echo Height—Echo Top - Echo Bottom
- Max dBZ Value—Maximum reflectivity value
- Height of Max Value—Altitude of the Max Value
- Center of Mass—Altitude of the center of mass of the reflectivity
- Vertically Integrated Liquid Water (VIL)—Estimate of the total water content in the column. VIL was computed by converting radar reflectivity to a liquid water equivalent using the exponential in-cloud drop size distribution proposed by Marshall and Palmer. (Marshall, 1948) The liquid water was subsequently integrated over the entire column. The physical units for VIL are $kg/m^2$. The equation used to generate VIL is:

  $$VIL = 3.44x10^{-6} \int_{0}^{15km} Z^{4/7} dh$$

  where Z is the equivalent reflectivity in units of $mm^6/m^3$ and dh is the vertical thickness of each Cartesian precipitation bin. Each column in this analysis was comprised of 15 vertically stacked bins each measuring 1km x 1km x 1km.

#### 2.2.4 Severe Storm Algorithm Products

This study also used the NEXRAD-derived hail, tornado, and mesocyclone products. These three products were generated using the National Severe Storms Laboratory (NSSL) Severe Storm Algorithm. Each of the products was two-dimensional:

- Hail—Probability of 0.75 inch hail in the storm
- Mesocyclone—Presence of rotation that is larger scale and weaker than tornadic rotation. (Tornadic thunderstorms often start out as mesocyclonic storms.)
- Tornado—Presence of at least 20 m/s gate-to-gate rotation in each of the NEXRAD's three lowest tilts. The regions of rotation must be "stacked" on top of each other (with some allowance for tilting of storms.)

### 2.3 Terminal Doppler Weather Radar (TDWR)

#### 2.3.1 Radar Locations

The DFW and DAL airports each have their own Terminal Doppler Weather Radar. Each radar is located approximately 10 miles from its respective airport. Figure 8 and Figure 9 show the regions of coverage for the DFW and DAL TDWRs.

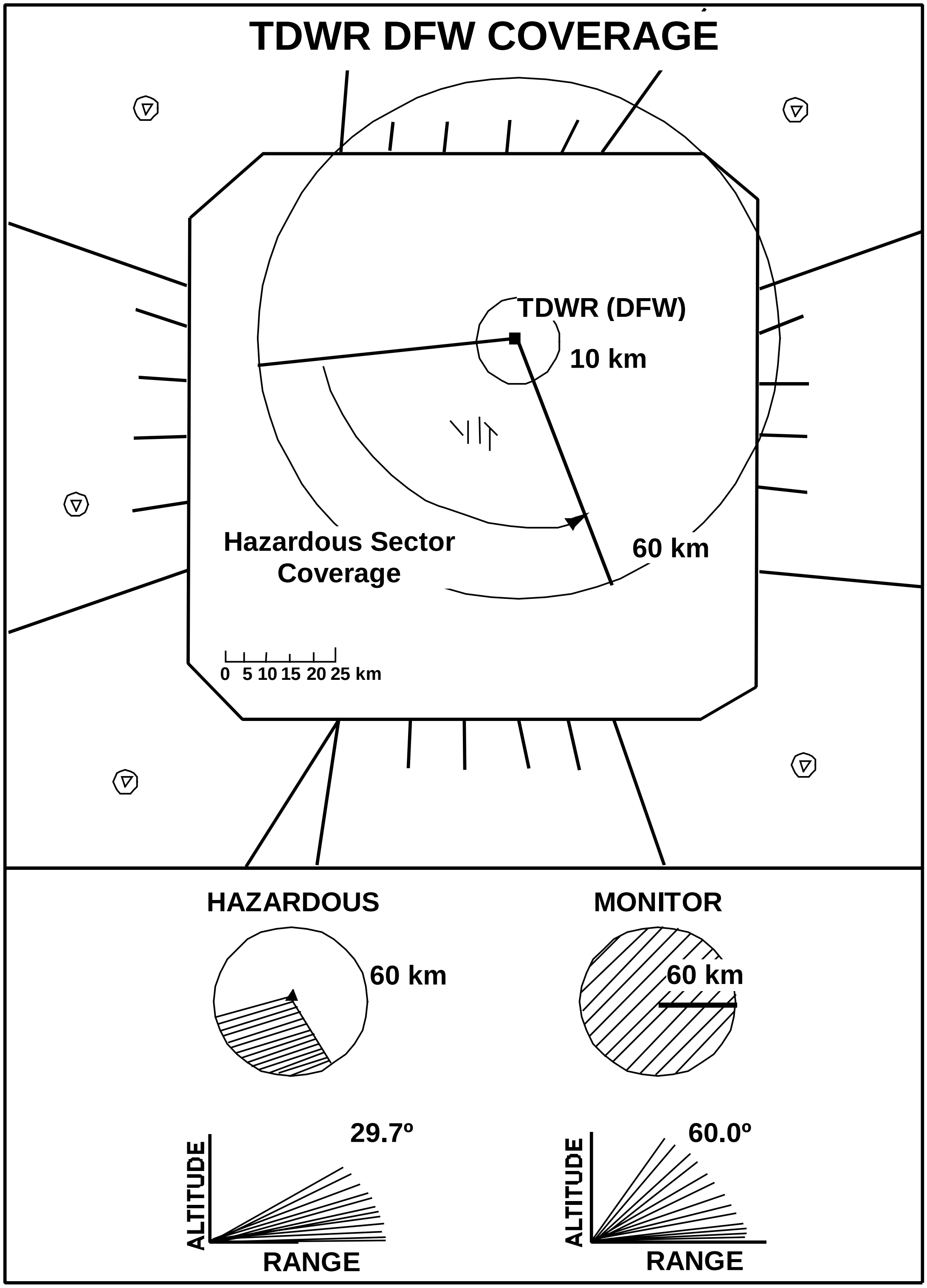



*Figure 8. The location and coverage region for the DFW TDWR. Data were used beyond 10km and within 60 km of the radar. The lower Figure shows a plan view of the scanning range and a vertical cross section of the scan strategy for the radar in "hazardous" and "monitor" modes.*

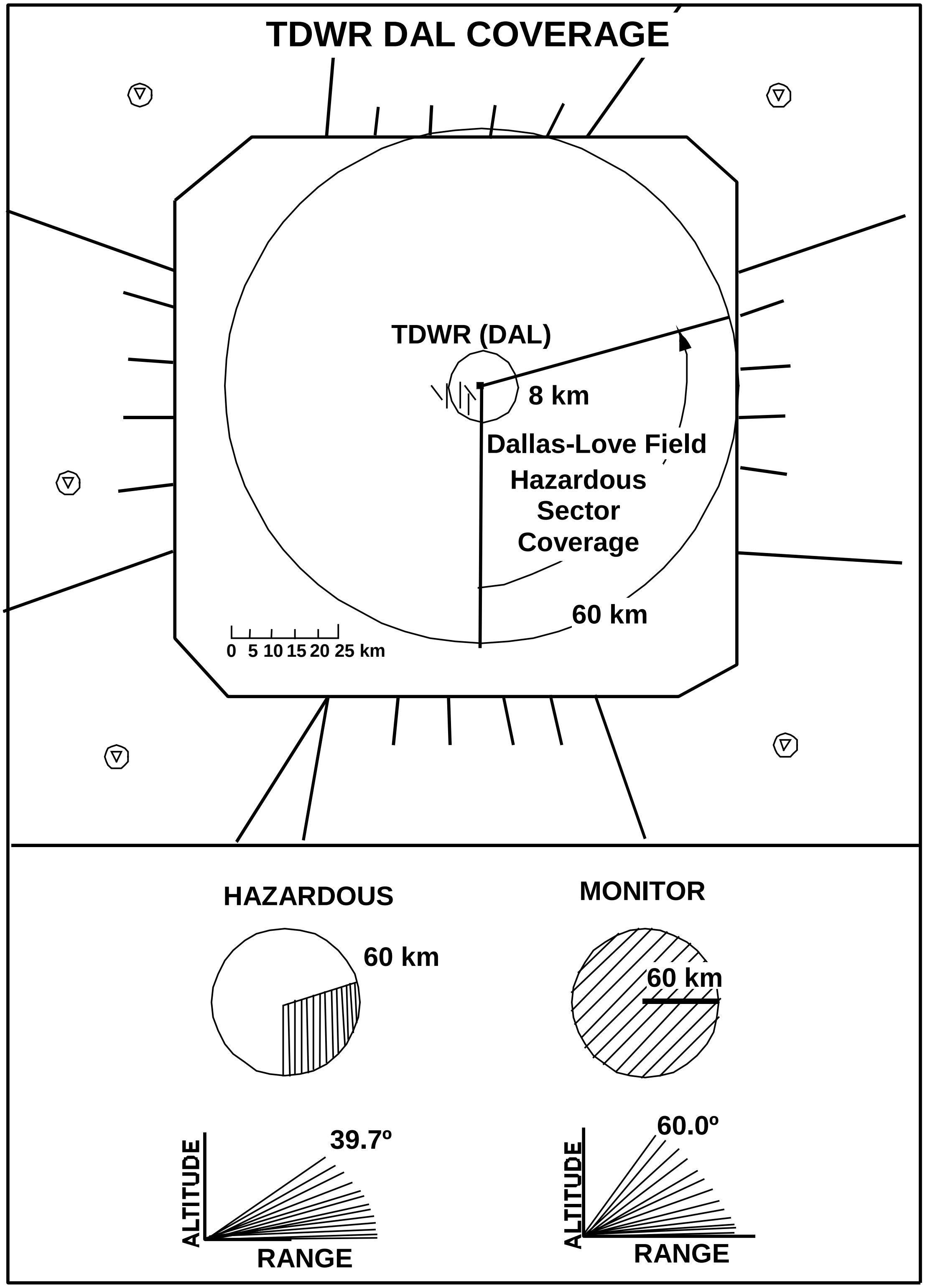



*Figure 9. The location and coverage region for the DFW TDWR. Data were used beyond 10km and within 60 km of the radar. The lower Figure shows a plan view of the scanning range and a vertical cross section of the scan strategy for the radar in "hazardous" and "monitor" modes.*

### 2.3.2 Scan Strategy

The TDWR, like the NEXRAD, operates in one of two modes. When there are no significant weather echoes within 45 km of the airport, the radar operates in monitor mode. In monitor mode, the radar performs 360 degree tilts, varying in elevation from a fraction of a degree up to 60 degrees. Once significant weather echoes develop, the radar switches to hazardous mode. In hazardous mode, the radar performs several 360-degree low-elevation tilts to detect gust fronts, and the radar performs the remainder of its tilts in a 100 to 120-degree sector over its airport to search for microbursts. When the radar is scanning in hazardous mode, the reflectivity product is 3D inside the hazardous sector and essentially 2D outside the sector.

The hazardous mode scan strategies differ slightly for the DFW and DAL radars because they are at slightly different ranges from their respective airports. The DAL TDWR scans up to 39.7 degrees of elevation in hazardous mode while the DFW TDWR scans up to only 29.7 degrees. Both TDWRs perform an entire volume scan in approximately 5 minutes in monitor mode and 2.5 minutes in hazardous mode.

### 2.3.3 Reflectivity-Based Products

The TDWR reflectivity-based products are conceptually identical to the NEXRAD products. See Section 2.2.3 for a description of the reflectivity-based products.

For the purposes of this study, in monitor mode the TDWR data were used for the entire 360-degree region around the radar from a range of 8 km (DAL) or 10 km (DFW) out to a range of 60 km from the radar. When the radars operated in hazardous mode, the seven 2D products were computed inside the hazardous sector only, where 3D radar coverage was complete.

### 2.3.4 Wind Shear Products

The study also examined two wind shear detection products which were derived from the DFW TDWR data:

- Wind Shear/Microburst—Maximum shear (divergence) in the detection. (Detected only within the DFW hazardous sector.)
- Gust Front—Strength of wind shear (convergence). (Detected over the entire region of DFW TDWR coverage.)

## 2.4 National Lightning Detection Network (NLDN)

The final weather product was a 2D map of cloud-to-ground lightning strikes as detected by the NLDN. The lightning flash rates were contoured into flashes per square kilometer per minute. The product covered the entire region of this study.

# 3 FLIGHT TRACK AND DELAY DATA

## 3.1 ASR-9 Flight Track Data

Flight track data were recorded in real-time from an ASR-9 on the DFW airport (DFW-W). The data included both flight plans and aircraft positions within 111 km (60 nautical miles) of the radar. Aircraft positions updated every five seconds. Data were collected for both arriving and departing flights. This study only considers the flights arriving at DFW or DAL airports. The data were post-processed to compute:

- Arrival fix used
- Runway used
- Path length flown inside the TRACON
- Arrival time
- Range of the encounter from the airport

## 3.2 Airline Service Quality Performance (ASQP) Data

The major airlines each submit a monthly report to the U.S. Department of Transportation listing each scheduled domestic flight and its scheduled departure time, scheduled arrival time, actual departure time, wheels-off time, wheels-on time, and arrival time.

The ASQP data were combined with the flight track data to identify aircraft that were already late when they initially reached the DFW airspace. The purpose of identifying late aircraft was to test the hypothesis that late pilots behaved differently than pilots who were not late. The results of the hypothesis test are reported in Section 6.4.2.

# 4 DATA PROCESSING AND REDUCTION

Once all of the weather and flight variables had been computed, the storm penetrations and deviations were identified. The flight data were used to extract the relevant weather data for each of these storm encounters. This set of weather data were reduced so that there was one value for each weather variable for each storm encounter. The following sections describe the data processing and reduction steps.

## 4.1 Identifying Storm Penetrations and Deviations

For all aircraft encounters with storms (penetrations and deviations), weather variables were extracted from the 2D and 3D Cartesian grids of data. All of the weather variables had 2D grids except for the reflectivity variable, DZ, which had a 3D grid. The data grids had “bins” of size 1km x1km (x 1km for the 3D grids) and there was a separate grid of data for each weather variable from each radar (ASR, TDWRs, and NEXRAD). The flight track data updated every 5 seconds, so multiple “observations” of the aircraft often occurred in the same Cartesian weather bin. The method by which penetrations were identified was different from the way deviations were identified.

### 4.1.1 Penetrations

An algorithm examined each flight and searched for instances where the aircraft entered weather that exceeded a penetration threshold for one or more variables. To avoid biasing the study results toward one sensor, there was a penetration threshold for one variable from each of the weather radars: Mosaicked ASR Precipitation (threshold of 2 on NWS six-level precip scale), TDWR VIL, and NEXRAD VIL (threshold of 2 $kg/m^2$). A penetration was defined to be a sequence of aircraft observations for which one or more of the variables exceeded its threshold. Figure 10 shows the flight track of an aircraft overlaid on six-level ASR precipitation. As the plane approached the DFW airport from the south, it penetrated levels 1, 2, 3, and 4 before reaching the airport. All of the observations defined to be within the 3D storm region were used to extract the weather data (see Figure 11). In Figure 10, approximately 20 aircraft location observations lie within the region of the storm cell. The radar observed the aircraft every 5 seconds so the penetration lasted about 100 seconds. The weather data retrieved from these 20 flight track observations were then further reduced to one value per weather variable per penetration (see Section 4.2).

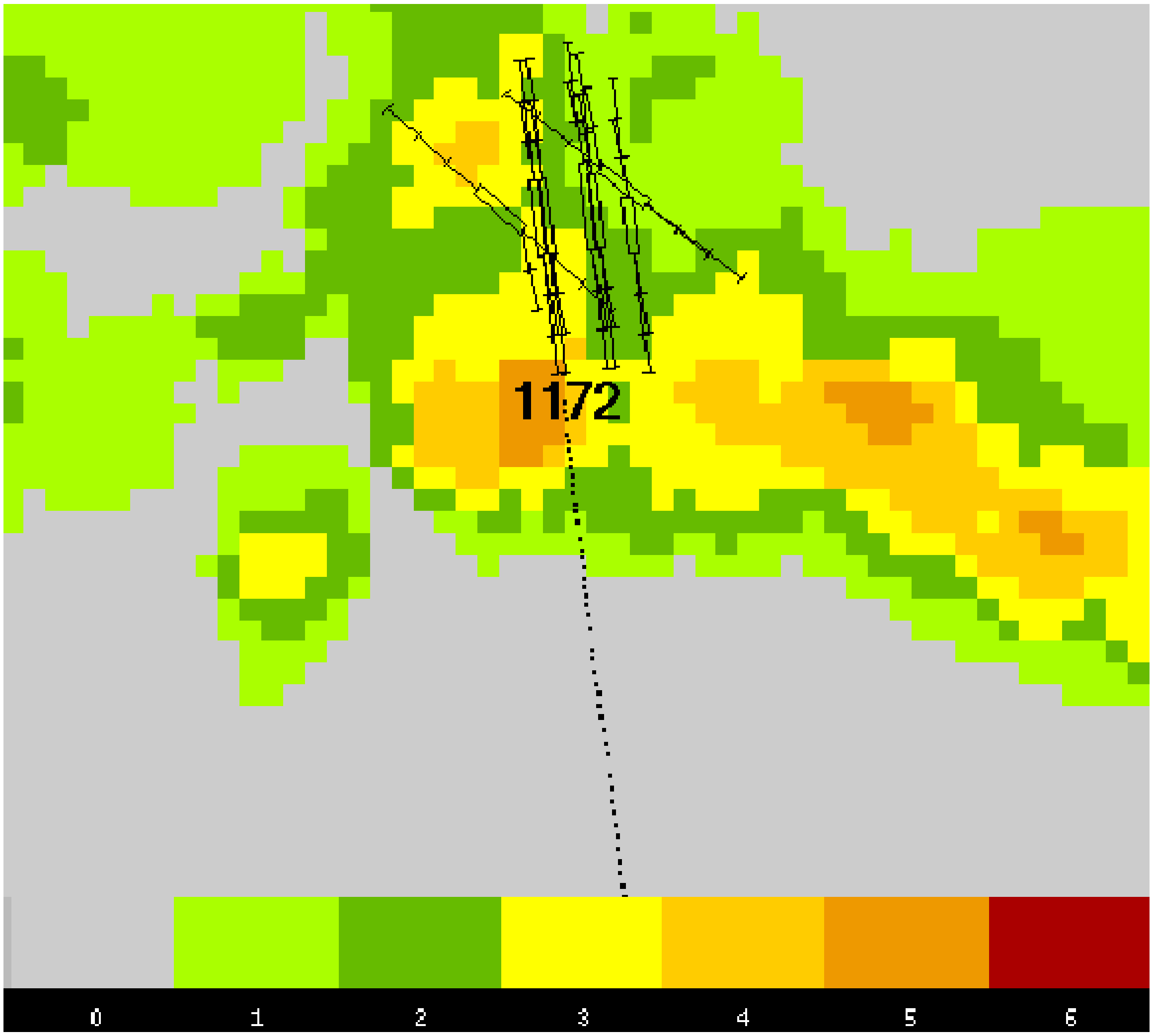



*Figure 10. Aircraft (with transponder code 1172) penetration of a thunderstorm.*

Some aircraft made several storm penetrations along their flight path. Penetrations that were on the order of tens of nautical miles long were sometimes broken into several penetration encounters if the aircraft penetrated more than one “hot spot” within the contiguous region of precipitation.

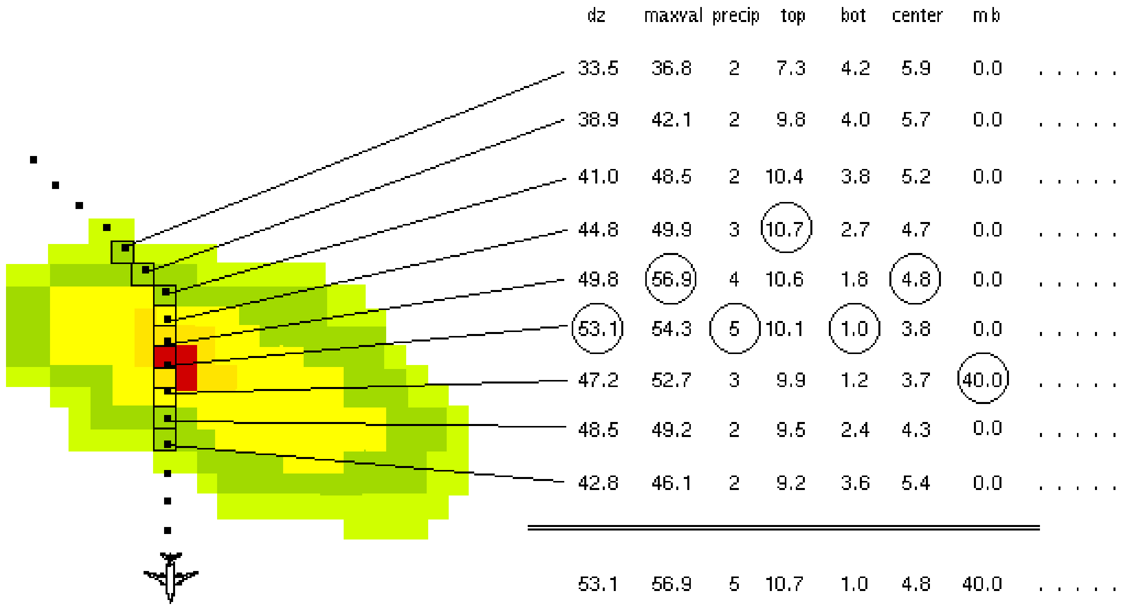



*Figure 11. Data are extracted from Cartesian bins occupied by the aircraft. One value of each variable is selected to characterize the penetrations.*

### 4.1.2 Deviations

It is difficult to have software automatically identify aircraft that deviate from their intended flightpath. In this study, a human analyst reviewed sequences of animated images of weather and flight track data and judged which aircraft deviated around weather. The analyst used software to draw a box around the weather that was believed to have caused each deviation. Figure 12 shows the flight track of an aircraft deviating around a storm cell with level 4 ASR precipitation, and an example of a box drawn by an analyst. Though this box was drawn by the analyst over a 2D picture, all of the weather data from the 3D region (the 2D box from the surface of the earth up to 15 km) were used (see Figure 13) to characterize the deviation. These data were then further reduced to one value per weather variable per deviation (see Section 4.2).

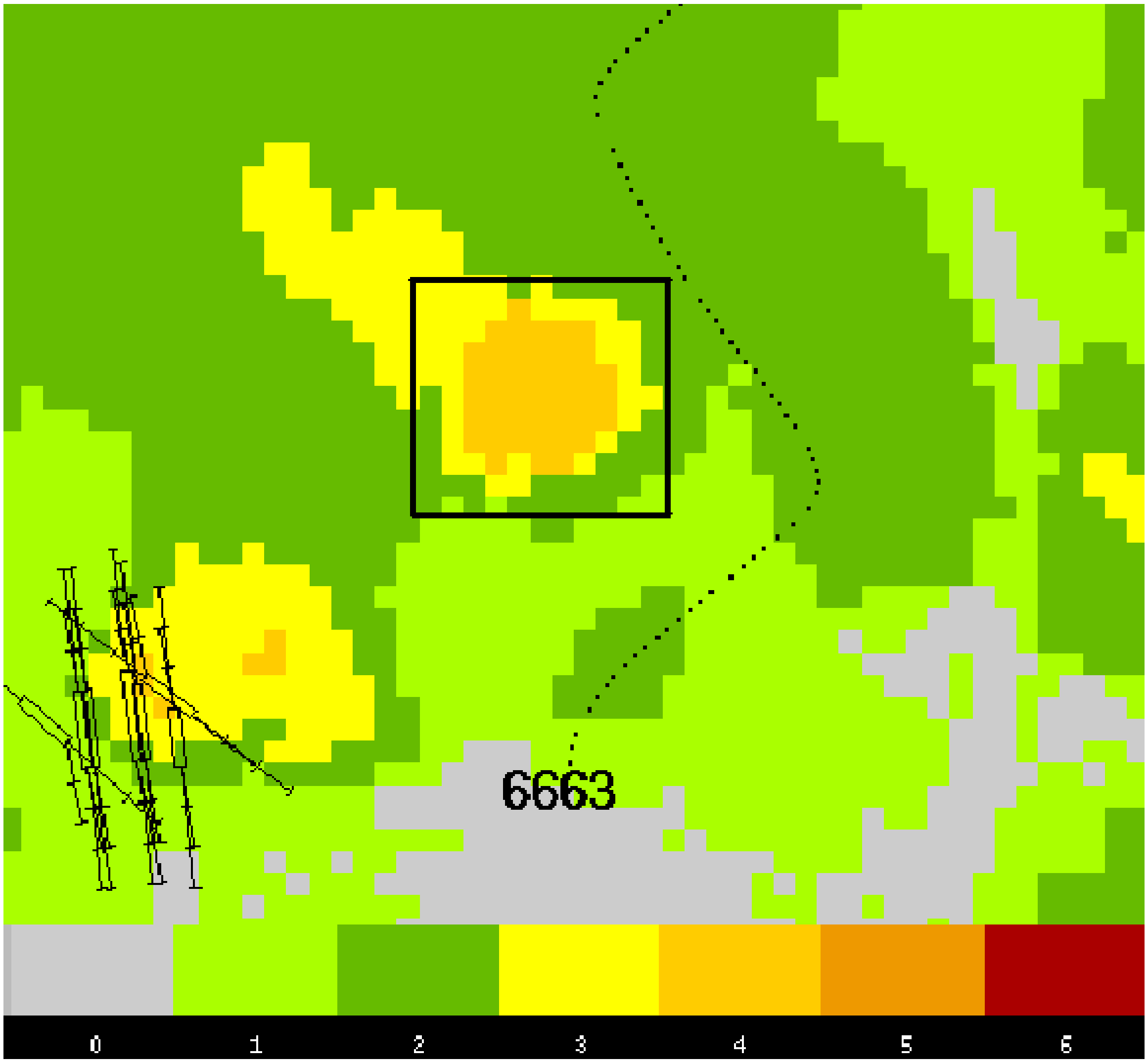
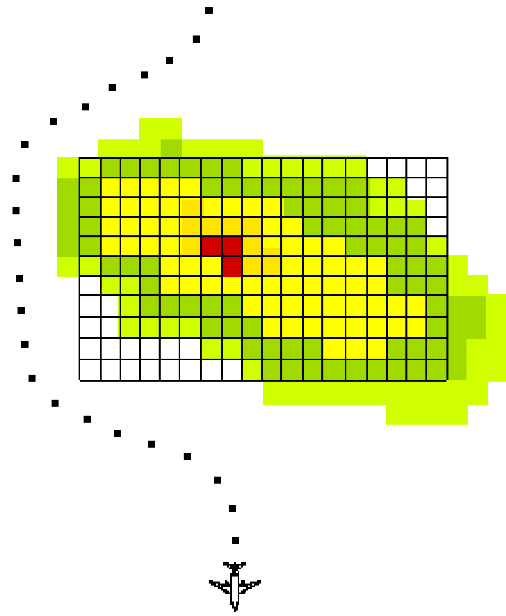



*Figure 12. Aircraft (with transponder code 6663) deviating around a storm cell.*



| dz | maxval | precip | top | bot | center | mb | |
|---|---|---|---|---|---|---|---|
| 33.5 | 36.8 | 2 | 7.3 | 4.2 | 5.9 | 0.0 | . . . . . . |
| 38.9 | 42.1 | 2 | 9.8 | 4.0 | 5.7 | 0.0 | . . . . . . |
| 41.0 | 48.5 | 2 | 10.4 | 3.8 | 5.2 | 0.0 | . . . . . . |
| 44.8 | 49.9 | 3 | 10.7 | 2.7 | 4.7 | 0.0 | . . . . . . |
| 49.8 | 56.9 | 4 | 10.6 | 1.8 | 4.8 | 0.0 | . . . . . . |
| 53.1 | 54.3 | 5 | 10.1 | 1.0 | 3.8 | 0.0 | . . . . . . |
| 47.2 | 52.7 | 3 | 9.9 | 1.2 | 3.7 | 40.0 | . . . . . . |
| 48.5 | 49.2 | 2 | 9.5 | 2.4 | 4.3 | 0.0 | . . . . . . |
| 42.8 | 46.1 | 2 | 9.2 | 3.6 | 5.4 | 0.0 | . . . . . . |
| . | . | . | . | . | . | . | |
| . | . | . | . | . | . | . | |
| . | . | . | . | . | . | . | |
| 53.1 | 56.9 | 5 | 10.7 | 1.0 | 4.8 | 40.0 | . . . . . . |

*Figure 13. For deviations, data are extracted from every Cartesian bin in the box defined by the analyst.*

## 4.2 Reducing the Data Associated with Each Encounter

Every penetration and deviation encounter in the data set was defined by multiple Cartesian bins. The data points for a penetration may be thought of as a three-dimensional string of Cartesian bins that encompass the sequence of aircraft observations during the storm penetration. The data points for a deviation comprise a 3D cube of Cartesian bins extending from the surface of the earth up to 15 km in altitude and filling the box that the analyst used to define the region of deviation. The data associated with each encounter were reduced to a single data point per variable by examining all of the Cartesian bins associated with the encounter and computing a representative value for each variable. The data reduction effort was accomplished in two steps per encounter.

First, since three pencil-beam radars were used in the study, there were multiple observations of the reflectivity-based variables at each observation point. None of the three pencil-beam radars covered the entire TRACON region, so the variables produced from each of those radars were combined into one representative value per variable per Cartesian bin. In Cartesian bins with multiple radar coverage, the maximum value of each variable was selected for analysis for all variables except echo bottom for which minimum value was selected and center of mass for which the median value was selected. There was a small region over the NEXRAD cone-of-silence where 3D reflectivity data were not available from any pencil-beam radar. (See Figure 14)

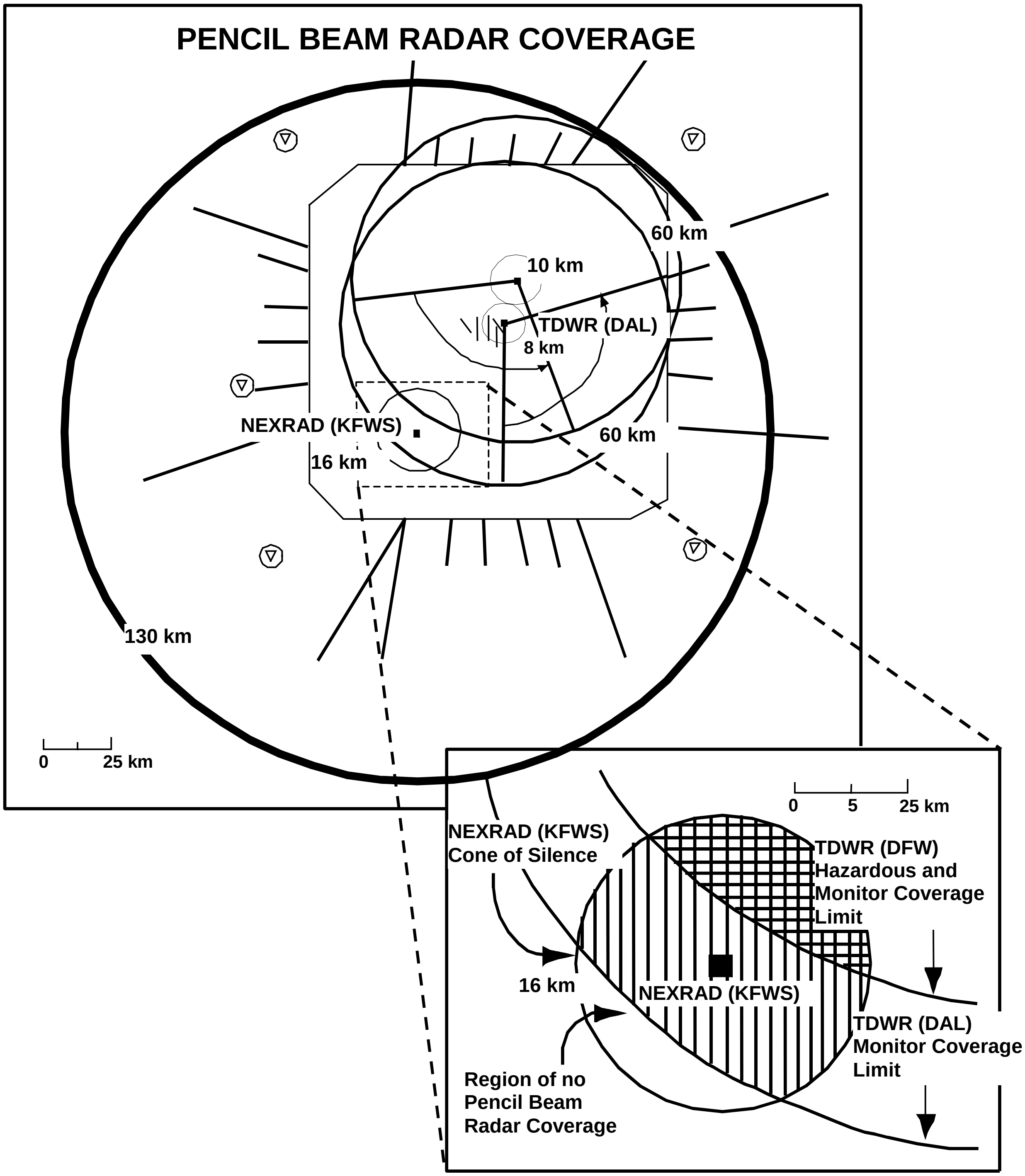



*Figure 14. Pencil-beam radar coverage regions inside the TRACON.*

After the variables from the three pencil-beam radars had been reduced to one value per variable per Cartesian bin, the set of data points was further reduced. Deviations and penetrations were reduced using the same procedure: all Cartesian bins associated with the encounter were examined and the minimum value of the echo bottom variable was selected as the representative value for the encounter, the median value was selected for the center-of-mass variable, and the maximum value was selected for each of the other variables.

# 5 STORM CELL ENCOUNTER DATA SET

## 5.1 General Description

The data set consists of 63 hours of weather and aircraft data from nine different days from the spring and summer of 1997 at Dallas Ft. Worth. See Table 2. During that 63 hour period, approximately 4300 aircraft arrived in the DFW TRACON intending to land at the DFW or Dallas Love airports. Out of 4300 arriving aircraft, 1279 had a total of 1952 encounters with storm cells. (Some individual aircraft had multiple encounters with storm cells.) Of the 1952 aircraft encounters with storm cells, there were 642 deviations and 1310 penetrations.

**Table 2.**
**Summary of Data Set**

| DATE | TIME (UT) | HOURS | # PEN | # DEV |
|---|---|---|---|---|
| 4/24/97 | 1530-1900 | 3.5 | 53 | 104 |
| 5/09/97 | 0130-0800 | 6.5 | 12 | 72 |
| 5/19/97 | 2030-0830 | 12.0 | 219 | 437 |
| 5/30/97 | 1845-0200 | 7.3 | 91 | 94 |
| 6/10/97 | 0030-0730 | 7.0 | 17 | 46 |
| 6/16/97 | 2130-0830 | 11.0 | 25 | 143 |
| 6/22/97 | 1845-2245 | 4.0 | 65 | 58 |
| 6/23/97 | 1600-2200 | 6.0 | 100 | 103 |
| 7/05/97 | 1300-1830 | 5.5 | 60 | 253 |
| TOTAL | | 62.8 | 642 | 1310 |

The 1952 encounters occurred over all parts of the TRACON. Figure 15 shows a histogram of the ranges (relative to the airport at which the aircraft was scheduled to land) at which the encounters took place. There were more encounters in the 10 - 30 km ranges due to the large number of aircraft that flew “downwind legs.” For example, an aircraft that enters the TRACON over the NW gate and lands on one of the northbound DFW runways, first flies southbound past the runway and turns completely around and flies northward to the runway.

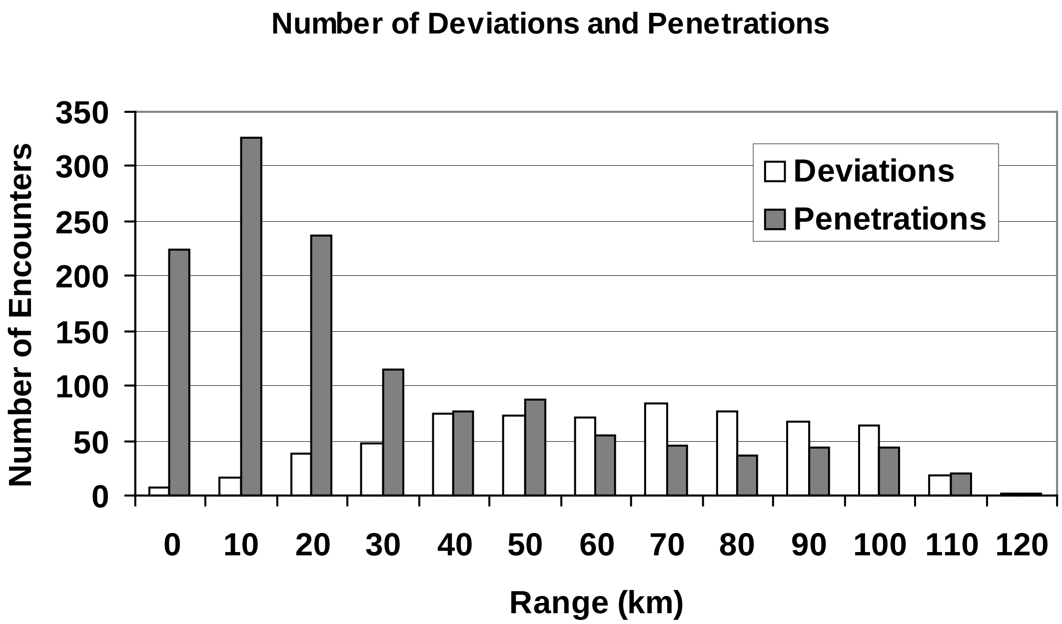



*Figure 15. Histogram of the number of penetrations and deviations as a function of range.*

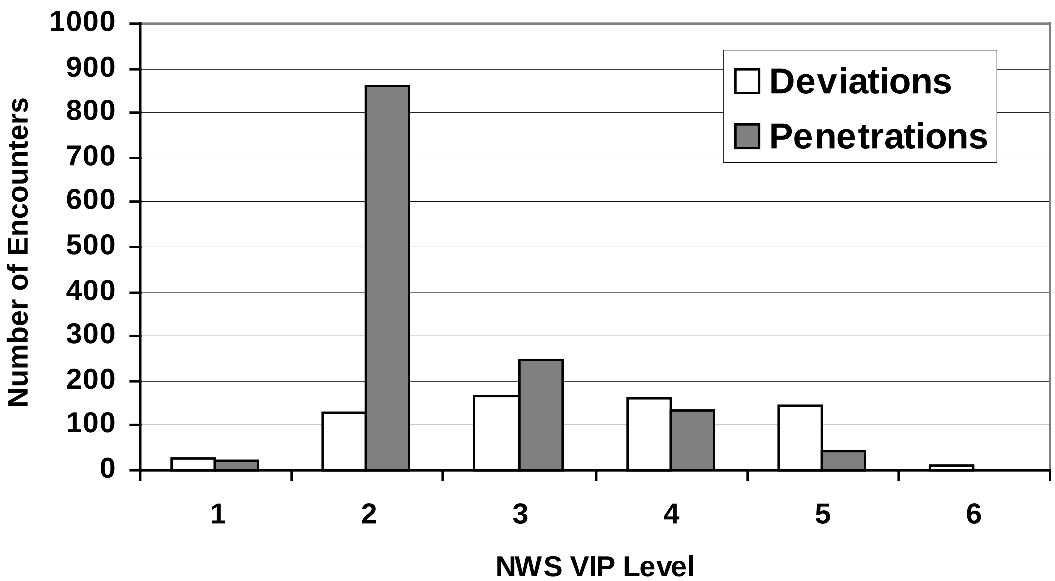



*Figure 16. Number of penetrations and deviations vs. ASR VIP level.*

Figure 16 shows a histogram of the ASR six-level precipitation for the penetrations and deviations. There were very few encounters with level 1 PRECIP in the data set due to the threshold values used to identify penetrations and deviations. (see Section 4.1.1). There were many penetrations of level 2. The number of deviations is larger than the number of penetrations for level 4+ weather. This corresponds well to the widely quoted rule-of-thumb that pilots begin to deviate when the weather reaches level 3 or greater.

# 6 STATISTICAL ANALYSIS

The foremost goal of this analysis is to determine which variables are best correlated with pilots' deviation behavior. The longer-term goal is to develop a classifier that could be used in real-time to generate a two-dimensional product that accurately represents the probability that pilots will deviate around the weather in the airspace. Although this analysis is not intended to develop or assess a long-term classifier, several statistical classifiers were trained and tested in this study.

The statistical analysis of the data was done in four steps. First the data were analyzed to find the combination of weather variables that best explained the variation in the penetration/deviation data. Second, several statistical classifiers were trained using those variables. Third, the classifiers were tested on a data set that was not used in the classifier training phase. The classifier training and testing phases of the analysis were restricted to weather variables only. A software package named LNKnet that was developed in the Information Systems Technology group at MIT Lincoln Laboratory is well suited to these three analysis tasks. (Lippmann, 1993) Finally, several hypotheses were tested on the flight variables.

## 6.1 Weather Variables and their Correlation to Deviation

The first step in the analysis was to determine which variables have explanatory power in the penetration/deviation decision. LNKnet is capable of methodically testing combinations of independent variables ("features") to find the combination with the most explanatory power. The entire data set was split randomly into two subsets; two-thirds of the encounters were assigned to the "feature selection and classifier training" subset and the remaining one-third were reserved in a "testing" subset.

Figure 15 indicates that there is very little variation in the deviation/penetration behavior near the airport. There may not be enough variation near the airport to correlate the behavior with any of the weather variables. Consequently the feature selection process was run on a) the entire training data set b) the subset of training encounters within 25 km of the airport, and c) the subset of training encounters that were more than 25 km from the airport.

### 6.1.1 Feature Selection on the Entire Training Data Set

LNKnet performed a forward-and-backward search through the weather variables employing a k-nearest-neighbors, leave-one-out technique to assess the explanatory power of various combinations of input variables. The best combination explained 94 percent of the variation in the data using just five variables: range from the airport, pencil-beam radar reflectivity (DZ), ASR precipitation level (ASR), percent of the TRACON quadrant covered in at least low-intensity (level 2+) precipitation, and percent of the TRACON quadrant covered in high-intensity (level 4+) precipitation.

The radar reflectivity variable alone explained about 80 percent of the variation in the data set. The magnitude of this variable's explanatory power is not surprising because most commercial aircraft are equipped with weather radar and a color display that indicates the presence of light, medium, or heavy rain. The ground-based radar reflectivity variable should correlate well with the airborne radar information available to the pilot.

It would not be practical, however, to design a probability-of-deviation classifier based on a 3D radar reflectivity product. In order to be helpful to air traffic planners and automation systems, a probability-of-deviation classifier needs to run on a forecast weather product; the system would need to predict the probability-of-deviation 20-30 minutes into the future. The technology to accurately forecast 3D storm structure 30 minutes into the future simply does not exist at this time. For the foreseeable future, a probability-of-deviation classifier will need to use a 2D representation of storm intensity. Therefore the LNKnet feature selection was run a second time without the radar reflectivity variable.

Without considering the 3D radar reflectivity variable, LNKnet found that 89 percent of the variation in the data can be explained by four variables: range from the airport, vertically integrated liquid water (VIL), percent of the quadrant covered in at least low-intensity (level 2+) precipitation, and percent of the quadrant covered in high-intensity (level 4+) precipitation. Seventy-four percent of the variation is explained by VIL alone. Again, it is not surprising that VIL has a great deal of explanatory power because VIL is computed solely from the 3D radar reflectivity variable.

Table 3 lists each of the storm intensity variables along with the amount of variation in the training data set that they explain individually.

**Table 3.**
**Percent Variation in Training Data Set Explained by a Single Storm Intensity Variable.**

| Storm Intensity Variable | Explanatory Power (Entire Training Data Set) | Explanatory Power (Encounters 25+ km From Airport) |
|---|---|---|
| 3D Radar Reflectivity (DZ) | 81 percent | 80 percent |
| Vertically Integrated Liquid Water (VIL) | 74 percent | 82 percent |
| ASR 6-Level Precipitation (ASR) | 74 percent | 73 percent |
| Maximum Reflectivity in Column (MAXVAL) | 69 percent | 73 percent |
| Echo Top | 61 percent | 60 percent |
| Lightning Flash Rate | 32 percent | 64 percent |

### 6.1.2 Feature Selection on Encounters Within 25 km of the Airport

LNKnet was not able to correlate any of the weather variables with the pilots' behavior near the airport. There were not enough deviations in that region to determine which variables are correlated with the deviation decision. This issue warrants further research.

### 6.1.3 Feature Selection on Encounters 25+ km from the Airport

The same feature selection process was run on the subset of training data that were 25+ km from the destination airports. The analysis excluded the 3D DZ variable. LNKnet found that 82 percent of the variation in the data set was explained by VIL alone. (See Table 3.) The two TRACON coverage variables explained another five percent of the variation in the data bringing the total to 89 percent.

### 6.1.4 Categories of Explanatory Variables

Broadly speaking, the feature selection portion of the data analysis indicates that there are three categories of variables that are strongly correlated with penetration and deviation behavior: storm intensity, weather coverage in the surrounding region, and range from the destination airport. The variables that are generally associated with in-flight hazards (microburst, gust front, hail, cloud-to-ground lightning flash rate, tornado, and mesocyclone) did not contribute any significant explanatory power to the overall penetration/deviation behavior. There were no tornadoes or mesocyclones in the storms in this data set. The lack of explanatory contribution of the other hazard variables are probably a combination of the facts that 1) those features may be strongly correlated with the reflectivity-based measures of storm intensity, and 2) pilots deviated around many storms for which the hazard-related variables indicated zero presence of the hazards.

#### 6.1.4.1 Storm Intensity

The relationship between storm intensity and pilots' deviation behavior is intuitive. Pilots are trained to avoid intense convection and the aircraft are equipped with radar to help the pilots detect and avoid strong storms. The following paragraphs elaborate briefly on DZ, VIL, MAXVAL, and ASR. Those four variables were used to train and test statistical classifiers in the subsequent phases of the analysis. The echo top and lightning flash rate variables fell quite low on the list of correlated variables so they were not used to train or test any classifiers.

*Pencil-beam radar reflectivity (DZ)*

The weather variable that was most strongly correlated with the pilots' penetration/deviation behavior was the intensity of the radar reflectivity as measured by the pencil-beam radars (i.e., NEXRAD and TDWR). This three-dimensional variable should be strongly correlated to the information available to the pilot via the airborne radar.

*Vertically Integrated Liquid Water (VIL)*

VIL is computed directly from the radar reflectivity variable and so it is also not surprising that the VIL variable is correlated with the deviation behavior. High VIL values are generally correlated with regions that have recently had very strong updrafts that "pull" a great deal of water into the airspace. The variable is often used as a proxy for storm intensity and high VIL values are one indicator of the potential for low level wind shear.

*Maximum reflectivity in the column (MAXVAL)*

MAXVAL is also computed directly from the radar reflectivity variable. It is often referred to as a "composite reflectivity" product and it is one of the products commonly available from weather data vendors. MAXVAL explains less of the variation in the deviation behavior than DZ because we lose information by characterizing the precipitation in a column by the maximum reflectivity value in the column. Aircraft may fly over or under the most intense precipitation in the column causing MAXVAL to underestimate the penetrability of the column. Also, in winter storms, the maximum reflectivity may be anomalously high due to "bright band" phenomena.

*ASR-9 Precipitation (ASR)*

Air traffic controllers' primary source of information about storms in the terminal area is the six-level weather channel on the Airport Surveillance Radar (ASR). Each controller can view any two of the six storm reflectivity levels (VIP levels) at one time on his or her Plan View Display (PVD). Air traffic controllers often say that, in general, aircraft do not penetrate airspace where the ASR weather channel shows level 3 or higher precipitation. The primary reason for its lower correlation with the penetration/deviation behavior is probably the fact that the ASR variable is quantized, taking on only integer values between zero and six.

#### 6.1.4.2 Weather Coverage

The dependence on weather coverage is also somewhat intuitive. If the storm being encountered is the only cloud in the sky then pilots often have plenty of latitude to deviate around the cell. If the area is covered in widespread precipitation then the pilot will likely have to fly through some precipitation to reach his/her destination and penetration becomes more likely. Finally, if the region is covered with strong convective activity, pilots tend to avoid the region altogether. Figure 17 shows the quadrant weather coverage variables for every encounter in the data set. Figure 18 shows the TRACON weather coverage values at the time of each encounter in the data set. The data set contains a wide variety of weather coverage situations but the data are sparse at the higher end of the domain.

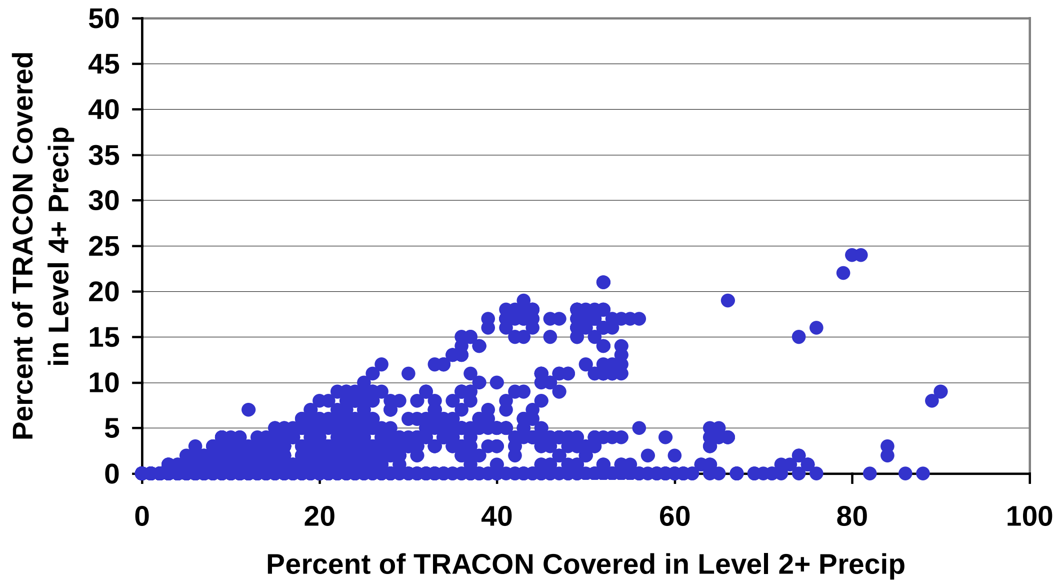



*Figure 17. Percent of the quadrant covered by level 4+ weather vs. percent of quadrant covered by level 2+ weather at the time of each encounter. Data are shown only for those quadrants where encounters took place.*

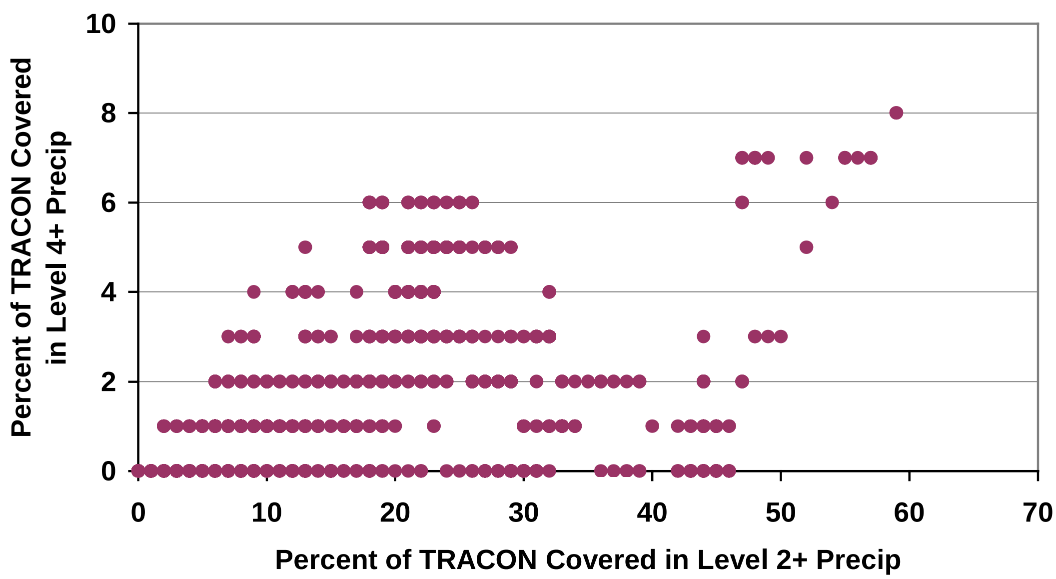



*Figure 18. Percent of the quadrant covered by level 4+ weather vs. percent of TRACON covered by level 2+ weather at the time of each encounter.*

6.1.4.3 Range

Pilots in this data set were more likely to penetrate intense thunderstorms near the destination airport than farther away. Within 25 km of the airport, 90 percent of the encounters with heavy weather (NWS level 3+) resulted in penetrations (266/297). Farther than 25 km from the airport, only 26 percent of the heavy weather encounters resulted in penetrations (157/611). Figure 15 shows the number of penetrations and deviations as a function of range from the airport. Figure 19 shows the penetrations and deviations in the entire data set as a function of range and storm intensity (VIL). Far from the airport the aircraft nearly always deviate around intense storms and nearly always penetrate weaker storms. Near the airport, the aircraft seem to penetrate the storms regardless of storm intensity. Indeed there is very little variation in the pilots' penetration/deviation behavior near the airport. It appears that the deviation criteria may change with range.

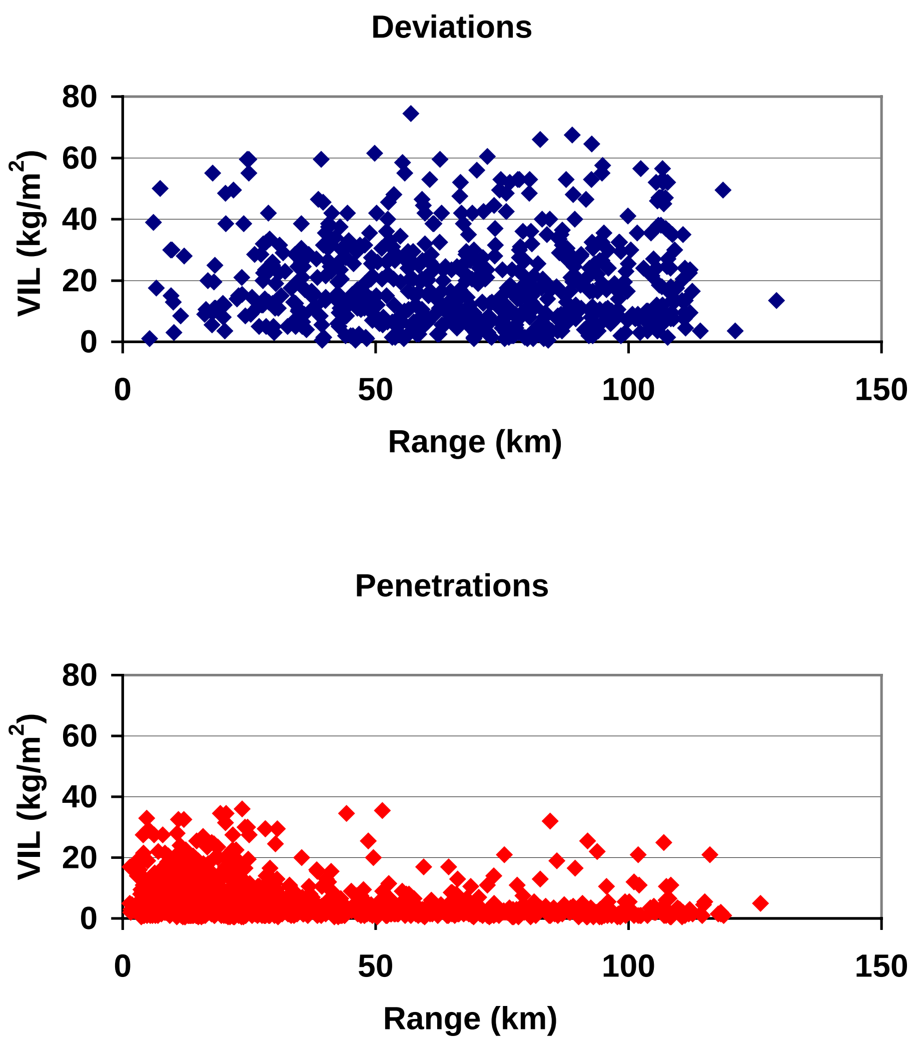



*Figure 19. Penetrations and deviations as a function of range and VIL. There are very few penetrations of high VIL values far away from the airport. There are very few deviations near the airport regardless of VIL value.*

Without talking to the pilots, it is impossible to say why they penetrated intense storms near the airport. It is worthwhile to point out that many of the factors associated with the penetration/deviation decision change as the aircraft approaches the airport:

- Approach routes have less lateral leeway for deviations without requiring that the aircraft be broken out of the landing sequence.
- Higher cockpit workload necessitates more heads-down time which leave less time for visual assessment of storms out the window.
- The on-board radar is subject to more clutter near the ground.
- The aircraft (and radar) are flying at altitudes below some of the thunderstorm "cores" and may be less able to assess the intensity of the storms.
- Multiple arrival streams of air traffic are merged together which makes it more likely that the aircraft in question is following closely behind other aircraft. Pilots are on a "party line" radio frequency with the air traffic controller and all of the pilots between themselves and the runway. Unpleasant rides and missed approaches are reported vocally.
- Air traffic controllers play a more active role in the dissemination of weather alerts. At many airports, the air traffic controllers have access to, and are required to pass along, real-time low-level wind shear alerts for the airspace near the airport. Controllers are not furnished with any alert information for storms farther away from the airport.
- Deviations are more likely to result in aborted approaches, airborne holding, and diversions. Figure 20 shows that aircraft that deviate near the airport fly paths inside the TRACON that are much longer, on average, than aircraft that deviate farther away from the airport or aircraft that penetrate storms at any range.

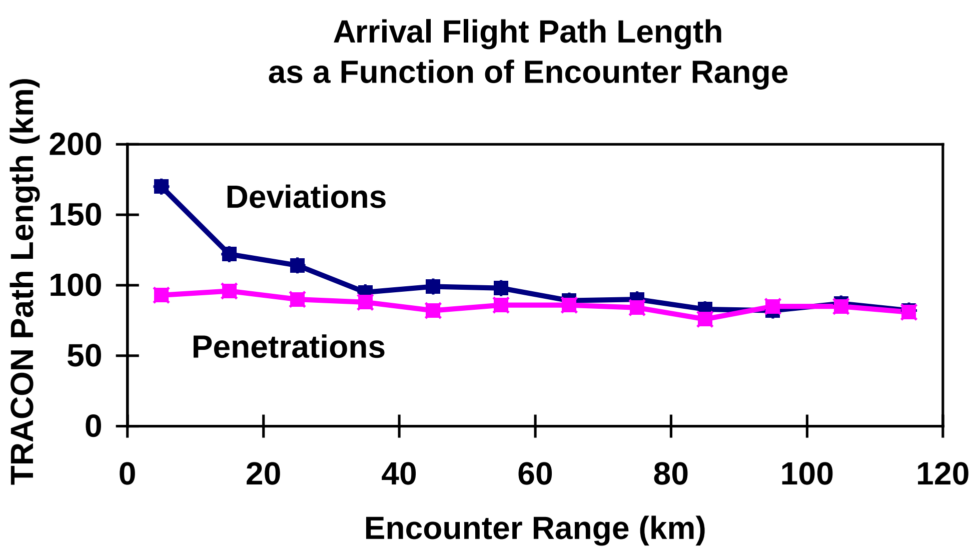



*Figure 20. Pathlength flown inside the TRACON as a function of encounter range. Aircraft that deviate within 25 km of the airport fly longer pathlengths on average than aircraft that penetrate. There is very little pathlength penalty, on average, for deviating around storms farther away from the airport.*

More research will be required to determine how these and other factors affect the pilots' ability to acquire information about the weather and their willingness to penetrate the weather. In any event, the fact that pilots penetrated level 3, 4, and 5 thunderstorms near the airport highlights the importance of wind shear alerting systems. [i.e., Low-Level Wind Shear Alert System (LLWAS), Terminal Doppler Weather Radar (TDWR), Integrated Terminal Weather system (ITWS), Airport Surveillance Radar (ASR) Weather Systems Processor (WSP)]

### 6.2 Statistical Classifier Training

There are several desirable properties for a storm cell encounter classifier that is intended be helpful to traffic planners and traffic automation systems:

- The classifier should yield probabilistic output; it should estimate the probability-of-deviation rather than simply classify airspace as deviation airspace or penetration airspace.
- The classifier should employ weather data only—the classifier should reliably compute the probability-of-deviation without knowing what types of aircraft are flying around, which airlines they belong to, or what order they are flying in.
- The classifier should be accurate over the entire domain of weather conditions upon which it would be expected to perform. It should be trained on many hours of data.
- The probability-of-deviation maps generated by the classifier should be forecast maps; the classifier should ingest forecast weather maps and generate forecast probability-of-deviation maps.

This analysis is not intended to fully address each of these concerns but rather to make an initial investigation into the factors that would contribute to an eventual classifier. The analysis does address the first two concerns; the classifiers that were tested do generate probabilistic output and it seems that the majority of the variation in the penetration/deviation behavior is explainable using weather variables only. The second two concerns are not addressed as directly as the first two. The 63 hour data set analyzed in this study does contain a large sample of encounters with a wide variety of thunderstorms, but the data set does not span the entire space of weather coverage variables and would therefore not be sufficient for generating a general purpose classifier. Finally, no attempt is made to restrict the analysis to those variables that are currently being generated by the thunderstorm forecast community.

LNKnet is capable of training neural networks, likelihood classifiers, nearest neighbor classifiers, rule-based classifiers, and committee classifiers. Both rule-based and neural network classifiers were trained and tested in this analysis. Rule-based classifiers consist of simple lists of nested "if" tests that divide the data space using lines or planes. The air traffic controllers' rule-of-thumb is a simple rule-based classifier. Neural networks combine the input variables using sigmoids to create ridge functions which in turn create decision regions in the input variable space. While the neural networks are more complicated than rule-based classifiers, they perform the same task—they divide the input variable space into decision regions that are associated with one of the output categories-in this application the two output categories were penetrations and deviations. Neural networks are attractive for this application because they not only estimate whether the storm cell encounter is more likely to result in a penetration or a deviation, they also estimate the numerical probability that the encounter will result in a penetration and the numerical probability that the encounter will result in a deviation. The probability estimates could be used both by human traffic managers via automated decision support tools, and by automation software itself. The following sections report results for neural network classifiers as well as a few simple rule-based classifiers.

Classifiers were trained and tested using the three categories of explanatory variables that were identified in the feature selection phase of the analysis: storm intensity, range, and weather coverage. Four storm intensity variables-DZ, ASR, MAXVAL and VIL-were used to train and test separate classifiers. Neural network classifiers were trained and tested on encounters in the 25+ km region and over the entire range of encounters. Neural net classifiers trained over the entire range of encounters employed a total of four variables: one storm intensity variable, the range variable, and the two quadrant weather coverage variables. Neural net classifiers trained on encounters 25+ km from the airport employed a total of three variables: one storm intensity variable and the two TRACON weather coverage variables. The rule-based classifiers employed only one storm intensity variable.

## 6.3 Statistical Classifier Testing

### 6.3.1 Classifier Performance

To make an unbiased estimate of a classifier's performance, the classifier needs to be tested on data that were not used in the feature selection or classifier training phases of the analysis. The measure of classifier performance reported here is the percentage of encounters in the test data set that were incorrectly classified (PIC). Low PIC values are desirable.

### 6.3.2 Measuring Neural Network Classifier Performance

Rather than use a simple threshold, the neural network classifiers combine the input variables using sigmoid functions to compute the probability that the encounter will result in a deviation and the probability that the encounter will result in a penetration. The two probabilities always add up to 100%. For the purpose of classifier performance, if the probability of deviation is computed to be greater than 50%, then the encounter was classified as a deviation. Otherwise, it was classified as a penetration. The classifications were compared to the real-world outcomes of the encounters to compute PIC.

### 6.3.3 Measuring Rule-Based Classifiers Performance

For each of the rule-based classifiers, LNKnet computed a storm intensity threshold for the purpose of predicting deviations. If the storm intensity variable exceeds the threshold, then the classifier predicts that the encounter will result in a deviation. Otherwise, the classifier predicts that the encounter will result in a penetration. Each classifier was tested on each encounter in the test data set and the classifier outputs were compared to the real-world outcomes of the encounters. The PIC numbers are reported in Section 6.3.6.

### 6.3.4 Training on Two-Thirds and Testing on One-Third of the Data

Four different classifiers were trained on the two-thirds of the data set that was used for feature selection. Each classifier employed a different storm intensity variable, DZ, VIL, MAXVAL, or ASR. The four classifiers were each tested on the one-third of the data set that was excluded from feature selection and classifier training. The classifier PICs are shown in Table 4. Note that the PICs for classification of penetrations are much lower than the PICs for deviations. The difference is explained by the preponderance of penetrations near the airport. The neural network classifiers are able to separate the encounters near the airport from the encounters farther away. The classifiers always predict penetration near the airport and therefore show very low PICs for those encounters. Four more classifiers were trained using only those encounters that occurred more than 25 km from the airport in the training data set. The classifiers were tested on the encounters more than 25 km from the airport in the test data set. Table 5 lists the resulting PICs. When the analysis was restricted to a region with a mix of penetrations and encounters, the penetration PICs increased to match or even slightly exceed the PICs for deviations.

**Table 4.**
**Neural net PICs for Classifiers Trained on Encounters at all Ranges. The PIC is the Percentage of Points in the Test Data Set that were Classified Incorrectly.**

| **Neural Net PICs: Train on 2/3—Test on 1/3<br>All Ranges<br>(Includes Range and Quadrant Weather Coverage)** | | | | |
|---|---|---|---|---|
| | **DZ** | **VIL** | **MAXVAL** | **ASR** |
| Deviations | 7 | 16 | 14 | 25 |
| Penetrations | 3 | 4 | 5 | 7 |
| Overall | 4 | 8 | 8 | 13 |

**Table 5.**
**Neural net PICs for Classifiers Trained on Encounters > 25 km from the Airport.**

| **Neural Net PICs: Train on 2/3—Test on 1/3<br>Encounters > 25 km from Airport<br>(Includes TRACON Weather Coverage Variables)** | | | | |
|---|---|---|---|---|
| | **DZ** | **VIL** | **MAXVAL** | **ASR** |
| Deviations | 5 | 14 | 13 | 18 |
| Penetrations | 13 | 17 | 21 | 41 |
| Overall | 9 | 15 | 17 | 29 |

The PICs in Table 4 and Table 5 are the best estimates of the rates that would be achieved on other data sets that span the same domain of weather variables as this training data set. If the classifiers are applied to data that lie outside the domain over which they were trained, the PICs might be substantially higher.

6.3.5 Training on Eight Days and Testing on One Day

To develop some intuition regarding the variability in PICs, a second approach was taken to training and testing the classifiers. The entire data set was separated into nine subsets where each subset corresponded to a day in the data set. For each day in the data set, DZ, VIL, MAXVAL, and ASR neural net classifiers were trained on eight days of data and tested on the ninth. Table 6 lists the averages and standard deviations of the PICs. The average PICs are slightly higher than the rates achieved in the two-thirds/one-third splits reported in Table 4 but they are still quite low. The standard deviations are fairly large when compared to the PICs which indicates that there is some variability in the day-to-day penetration/deviation behavior. Some of the variation might also reflect the fact that there was some day-to-day variation in the location of the storm cells with respect to the airport. See the appendix for a description of each of the storm days.

**Table 6.**
**Averages and Standard Deviations of Neural Network Classifier PICs for Eight Day Training/One Day Testing Splits. All Ranges.**

| **Train on 8 Days—Test on 1 Day<br>Average PICS/Standard Deviations—All Ranges** | | | | |
|---|---|---|---|---|
| | **DZ** | **VIL** | **MAXVAL** | **ASR** |
| Deviations | 11/7 | 23/11 | 20/10 | 32/11 |
| Penetrations | 5/5 | 7/5 | 10/8 | 13/9 |
| Overall | 6/4 | 11/5 | 12/5 | 18/7 |

Table 7 lists the average PICs and their standard deviations for the eight days/one day splits for encounters that occurred more than 25 km from the airport. The classifiers each employed one storm intensity variable and the two TRACON weather coverage variables. The PICs on the penetration encounters are higher than those in Table 6 because the easy-to-classify encounters near the airport have been removed from the data set.

**Table 7.**
**Averages and Standard Deviations of Neural Network Classifier PICs for Eight Day Training/One Day Testing Splits. Ranges > 25 km from the Airport.**

| **Train On 8 Days—Test on 1 Day<br>Average PICS/Standard Deviations—Range > 25 km** | | | | |
|---|---|---|---|---|
| | **DZ** | **VIL** | **MAXVAL** | **ASR** |
| Deviations | 11/8 | 19/10 | 17/9 | 26/13 |
| Penetrations | 13/12 | 18/15 | 19/12 | 24/25 |
| Overall | 10/6 | 17/9 | 17/8 | 24/14 |

Overall, the classifier testing results are quite encouraging. These data indicate that two-dimensional weather variables may be used to construct a classifier that correctly classifies more than 80 percent of storm cell encounters in these test data sets. Furthermore, the neural network classifiers estimate the probability of penetration and deviation which implies that it may be possible to train a classifier that will ingest two-dimensional weather data and generate reliable probability-of-deviation maps.

The classifiers do not, however, exhibit any skill near the airport. Figure 21 shows the probability-of-deviation values generated by a neural net classifier as a function of range and weather-coverage. The storm being encountered in this example is a level 6 cell with a VIL value of 40 kg/m$^2$. The three curves represent different values of the light weather quadrant coverage variable. The heavy weather quadrant coverage variable is held constant at 10 percent. The classifier yields unrealistically low probability values in the 0 to 30 km region. All of the classifiers trained in this analysis yield similarly low probability-of-deviation numbers near the airport regardless of the weather intensity. Again, more work will be necessary to determine whether it will be possible to generate reliable probability-of-deviation maps near the airport.

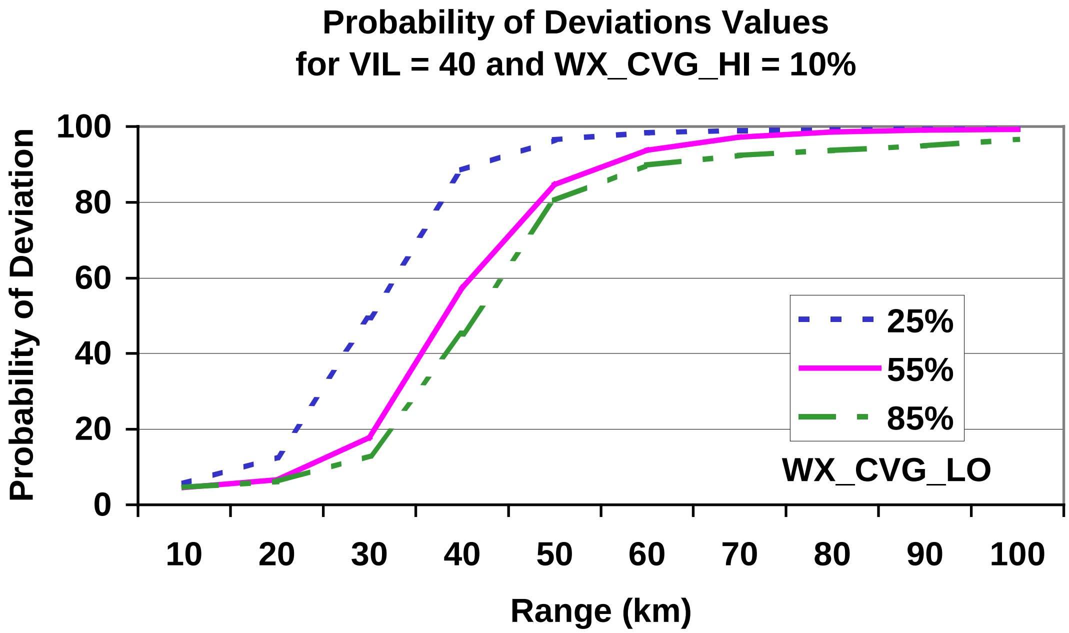



*Figure 21. Neural net classifier output. Probability of deviation around a level 6 storm cell as a function of range and weather coverage. The classifier predicts unrealistically low probability of deviation near the airport.*

6.3.6 Simple Rules-of-Thumb

Four simple binary tree classifiers were trained on the training data set and tested on the remaining third of the data set. The classifiers were designed to split the data using only one storm intensity variable and using only one node. The resulting classifiers are simple rules-of-thumb which are corollaries to the controllers' oft-quoted rule-of-thumb. Table 8 lists the resulting storm intensity thresholds and PICs for the classifiers trained on the entire training data set. Table 9 lists the thresholds and PICs for the classifiers trained on the encounters that occurred more than 25 km from the destination airports.

Note that the controllers' rule-of-thumb is validated for encounters far from the airport. LNKnet agrees that the lowest PIC is achieved by classifying encounters with level 1 and 2 storms as penetrations and classifying encounters with level 3+ storms as deviations. Furthermore, the VIL threshold, 6 kg/m$^2$, corresponds to a level 3 cell on the ASR precipitation scale which also corroborates the controllers' rule-of-thumb. (See Figure 3.) When the entire data set is considered, the ASR variable does not corroborate the rule-of-thumb. Rather, it indicates that the lowest PIC is achieved by predicting that pilots will always penetrate the weather. That result is due to the large number of heavy weather penetrations near the airport in this data set.

Finally, it is noteworthy that the rule-of-thumb classifiers achieve PICs similar to those of the neural net classifiers for the encounters that are far from the airport. (See Table 7.) The chief advantage of the neural net classifiers far from the airport is that they yield probabilistic results rather than simply assigning encounters to the penetration and deviation categories.

**Table 8.**
**Binary Tree Classifier Thresholds and PICS.**
**(The classifiers predict that pilots will deviate if the storm intensity variable exceeds the threshold value.)**

| **Rules-of-Thumb Based on Training Data Set Over All Ranges** | | | | |
|---|---|---|---|---|
| | **DZ** | **VIL** | **MAXVAL** | **ASR** |
| Threshold | 51 dBZ | 6 $kg/m^2$ | 49 dBZ | Always Penetrate |
| Deviations | 14 | 14 | 15 | 100 |
| Penetrations | 11 | 26 | 23 | 0 |
| Overall | 12 | 22 | 20 | 33 |

**Table 9.**
**Binary Tree Classifier Thresholds and PICS for Encounters 25+ km from Airport.**
**(The classifiers predict that pilots will deviate if the storm intensity variable exceeds the threshold value.)**

| **Rules-of-Thumb Based on Training Data Set When Range > 25 km** | | | | |
|---|---|---|---|---|
| | **DZ** | **VIL** | **MAXVAL** | **ASR** |
| Threshold | 47 dBZ | 6 $kg/m^2$ | 51 dBZ | Level 3 |
| Deviations | 9 | 14 | 21 | 20 |
| Penetrations | 13 | 20 | 15 | 27 |
| Overall | 11 | 17 | 18 | 24 |

## 6.4 Part four: Hypothesis Tests with Flight-Related Variables

Several flight-related variables in the study were well-suited for hypothesis tests that yielded interesting results.

### 6.4.1 Leaders and Followers

Hypothesis: Aircraft that encounter heavy weather are more likely to penetrate the weather if another aircraft has flown through that airspace recently.

Several previous studies have found evidence that pilots pay attention to ride reports from preceding pilots and factor those reports into their decision-making process (Midkiff, 1992; Hyams, 1998). The scope of this study did not include the collection and analysis of radio voice communications but it is possible to examine whether the presence of a preceding aircraft is correlated with the behavior of following aircraft.

The data indicate that there is, indeed, a correlation between the pilots' penetration behavior and the presence of preceding pilots. Aircraft that followed closely behind a preceding aircraft were more likely to penetrate heavy weather than aircraft that did not. In this study, "leaders" were defined to be aircraft who flew along a route that had not been used by a preceding aircraft for at least ten minutes. Followers were aircraft that flew along a route that had been used by another aircraft within the preceding ten minutes. Twenty-six percent of the leaders that encountered heavy weather in this data set (79/298) penetrated the storms. Fifty-six percent of the followers that encountered heavy weather (344/610) penetrated the weather. When the analysis is restricted to encounters with heavy weather within 25 km of the airport, the percentages increase. Forty-three percent of the leaders penetrated the storms (22/51) and 93 percent of the followers did so (211/220). These differences are statistically significant at the 0.01 level.

### 6.4.2 Aircraft Behind Schedule

Hypothesis: Aircraft that take longer than normal to reach the TRACON boundary of the destination airport are more likely to penetrate heavy weather than aircraft that are on-time or early.

Aircraft flying in to DFW or DAL first appear on the DFW-W airport surveillance radar when they are 60 nautical miles from the DFW airport. From that point, it typically takes 20 minutes to fly to the DFW or DAL airports. In this study, aircraft that arrived at the radar boundary having already flown 15 minutes longer than the scheduled flying time to that point in the trip (i.e., within five minutes of the scheduled flying time for the entire trip) were more likely to penetrate heavy weather than those that arrived earlier.

Fifty-one percent of the encounters with heavy weather made by "late" planes (39/77) resulted in penetrations. Only 15 percent of the heavy weather encounters made by aircraft that were not "late" (79/531) resulted in penetrations. The difference between the early and late aircraft's propensity to penetrate is significant at the 0.01 level. [Note. The scheduled flying times were not available for all of the aircraft that encountered heavy weather.]

The result holds even when the analysis is restricted to encounters that took place far from the airport. Eighteen percent of the early encounters with heavy weather more than 25 km from the airport resulted in penetrations. (31/175). Thirty-nine percent of the late encounters with heavy weather more than 25 km from the airport resulted in penetrations. (14/36) The difference between the early and late aircraft's penetration percentages are statistically significant at the 0.01 level.

### 6.4.3 Aircraft that turn vs. aircraft that do not turn

Hypothesis: Aircraft that make several turns near the airport are more likely to penetrate heavy weather than aircraft that fly in a straight path from the TRACON arrival fix to the runway.

There are three reasons for suggesting that turning aircraft might be more likely to penetrate heavy weather than those that fly straight to the runway:

1. There is a higher cockpit workload associated with flying an approach with downwind and base legs of flight than a straight-in approach. Aircrews with higher workloads might have less time to visually assess the radar or to manipulate onboard radar controls.
2. Onboard radars might experience a great deal of ground clutter while banking during a turn.
3. Aircraft may turn and fly into airspace where the radar was not previously able to scan.

The structure of the DFW airspace and runways allow us to test this hypothesis with the current data set. DFW has five north-south runways and two diagonal runways. Some of the DFW-bound aircraft cross the southeast cornerpost of the TRACON and fly directly to the diagonal runway 31R. Others of the inbound traffic cross the northwest cornerpost and fly directly to the diagonal runway 13R. When the runway is in a northbound landing configuration, any traffic that enter the TRACON from the north and land on runways 35 or 36 must fly downwind and base legs of flight. Similarly, aircraft that enter the TRACON from the south and land to the south must fly downwind and base legs of flight. The data set analyzed here contains aircraft in each of these categories. To test the hypothesis we need only separate the data set into those that turn, those that don't, and those for which the turns are slight. (Aircraft that enter from the north and land to the south and aircraft that enter from the south and land to the north are left out of the hypothesis test because their turns are not particularly sharp.) Figure 22 shows the nominal flight paths of the aircraft that are included in the hypothesis test.

There is no statistically significant difference in the two groups' penetration/deviation behavior. Eighty-five percent of the turning pilots who encountered level 3+ weather within 25 km of the airport, penetrated the weather. (67/79) Eighty-eight percent of the pilots who flew straight in to the runways and encountered level 3+ weather within 25 km of the airport, also penetrated the weather. (14/16)

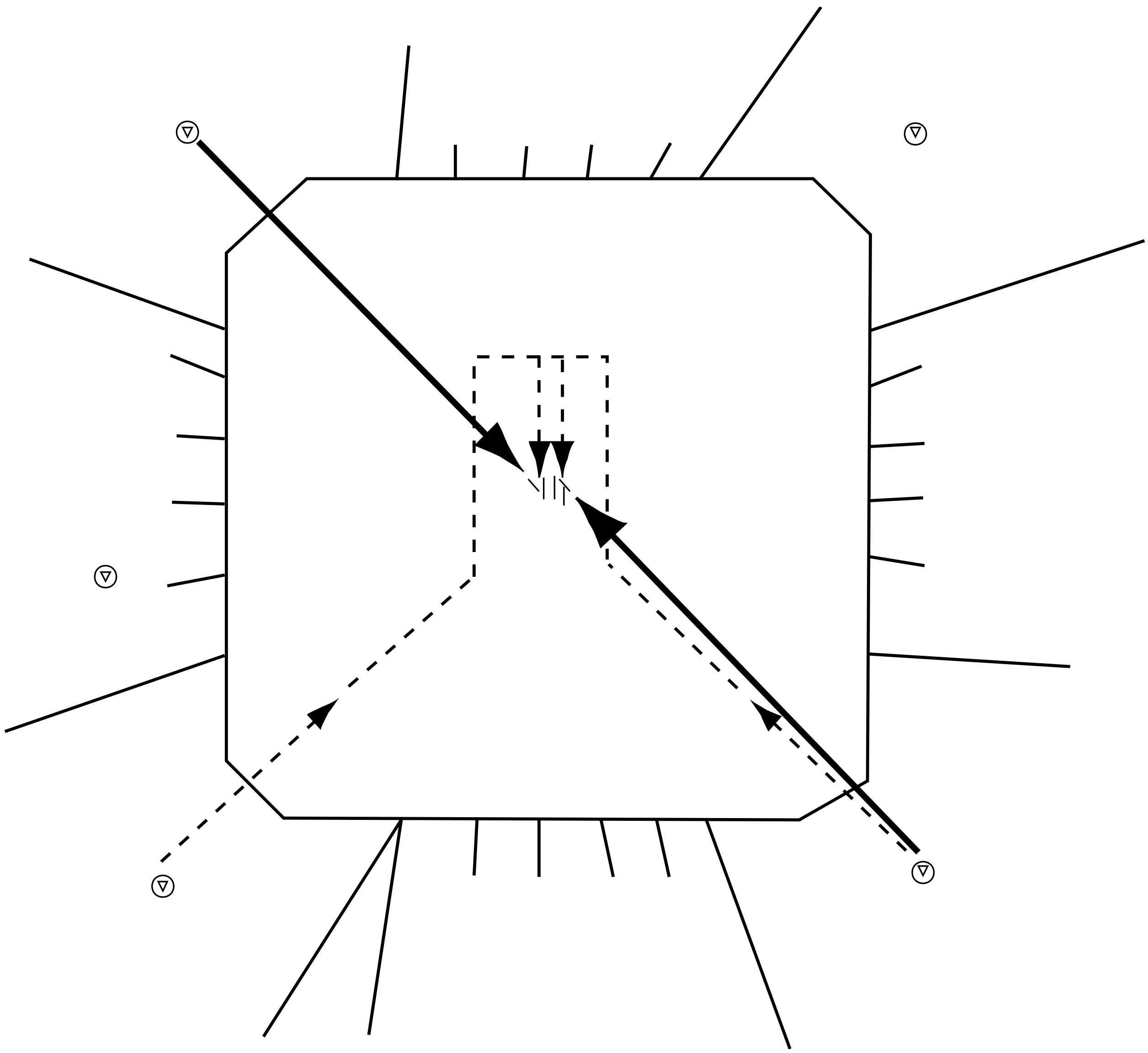


*Figure 22. Flightpaths of aircraft included in the hypothesis test. The solid black lines represent aircraft that flew straight from the northwest and southeast cornerposts to their destination runways. The dashed lines represent aircraft arriving from the south that needed to turn in order to execute downwind and final legs of flight before landing.*

6.4.4 Various Airlines

Hypothesis: Some airlines are more likely to penetrate weather than others are.

Seven airlines had more than 20 encounters with light weather (level 1 or 2) in the data set. There were no statistically significant differences in the airlines' propensity to penetrate or deviate around light weather. Six airlines had more than 20 encounters with heavy (level 3+) weather in the data set. There were no statistically significant differences in the airlines' propensity to penetrate or deviate around the heavy weather.

6.4.5 Time of Day and Lightning Flash Rate

Hypothesis: The propensity of aircraft to deviate around clouds containing cloud-to-ground lightning in the daytime differs from the propensity to deviate at night.

Lightning flashes are more difficult to see in the daytime than at night. If pilots use the presence of lightning to identify convective cells after dark then we might see more deviations around electrified cells at night. Four of the nine days in the data set extended into the night. Each encounter in the data set was classified as either a daytime or a nighttime encounter. Nighttime encounters were defined to be those that occurred more than one hour after twilight. The encounters were also separated into three categories of lightning flash rate: no lightning, minimal lightning (0-3 flashes/min/km), and strong lightning(>3 flashes/min/km).

Table 10 shows the six categories of encounters along with the percent of each category that resulted in deviations. There is indeed a difference between the daytime and nighttime deviation percentages but the difference is counter to the reasoning in the previous paragraph. In each category of lightning flash rate, there are twice as many deviations (by percentage) in the daytime as at night!

**Table 10.**
**Deviations as a Function of Lightning Flash Rate and Time of Day.**

| | **Number of Encounters** | | **Percent Deviations** | |
|---|---|---|---|---|
| | **Day** | **Night** | **Day** | **Night** |
| No Lightning | 983 | 262 | 27 | 11 |
| Minimal Lightning | 252 | 36 | 43 | 14 |
| Strong Lightning | 377 | 42 | 60 | 31 |

Based on this data set it is impossible to determine exactly why pilots deviated around more electrified cells during the day than at night. Several possible explanations warrant further investigation: First, the pilots may use the visual appearance of the storms in the daytime to help make the deviation decision. Second, although the lightning flashes should be visible after dark, the flashes may be scattered and reflected by other clouds and it may be difficult for pilots to identify which storm cells generate the flashes. Third, daytime and nighttime storms in this data set may differ in some way that is not captured in the cloud-to-ground lightning flash rate categories.

# 7 CONCLUSIONS

This analysis investigates which weather variables are correlated with arriving pilots' storm cell penetration/deviation behavior in the DFW terminal airspace. Far from the airport, the pilots' behavior is well correlated with a small number of weather variables. Three-dimensional data yielded the best correlation but two-dimensional storm intensity variables were also strongly correlated with the pilots' behavior.

The report indicates that it is possible to train a statistical classifier that characterizes the probability that pilots will penetrate or deviate around airspace occupied by thunderstorms. The analysis outlines several desirable characteristics of a probability-of-deviation classifier. The classifiers trained and tested in this study were able to correctly classify more than 80 percent of the storm cell encounters in an independent data set. Those classifiers could be used as a starting point for evaluating the utility of probability-of-deviation maps in automated decision aid tools-particularly for those regions of the TRACON more than 20-30 km from the airport.

The analysis does not find any correlation between the weather variables and the pilots' penetration/deviation behavior near the destination airports. The vast majority of encounters near the airport in this study resulted in penetrations. Pilots penetrated storms with precipitation intensities of NWS level 3, 4, and even 5.

Furthermore, arriving aircraft in this data set were more likely to penetrate storms when they were:

- Following another aircraft,
- More than 15 minutes behind where they ought to be based on the nominal flying time scheduled for the trip, or
- Flying after dark.

## 8 RECOMMENDATIONS FOR FUTURE WORK

This study points to a number of logical follow-on studies:

1. The study should be repeated in the en route airspace. The study should account for whether the aircraft are flying at cruise altitude or whether they are transitioning to/from terminal airspace. Aircraft in the en route airspace sometimes fly over the top of thunderstorms. The study should examine the altitude of the aircraft with respect to the altitude of the storms. The en route study could address the following questions:
   - Which weather products should be displayed in the WARP system?
   - How many vertical levels of weather information are necessary in the en route regime?
   - What representation of weather should be incorporated into conflict probe tools?
2. Data should be analyzed for departing aircraft in the terminal area.
3. More DFW data should be analyzed—data from all different times of the year.

   The most labor-intensive portion of this analysis was the identification of deviating aircraft. To process more data, it would be very helpful to automate the process of deviation detection.

   To understand the decision-making process employed in encounters near the airport, future studies should use voice recordings and wind shear alert archives to record whether the pilots received wind shear alerts, microburst alerts, and pilot reports. It seems likely that these information sources—which were not included in the present study—are important factors in the penetration/deviation decision in that region.

   Statistical classifiers should be trained and tested on a larger number of days of data. The classifiers should be run on "real" weather maps and "forecast" weather maps to generate probability of deviation (PODEV) maps. The PODEV maps should be evaluated by several different methods:
   - Examine a large number of aircraft encounters with storms and determine whether the PODEV maps yield reasonable values. Score the low, medium, and high values of PODEV to determine whether the values correspond to pilot behavior in a statistical sense. (e.g., Do approximately half of the encounters with storms that have a PODEV of 50 percent result in deviations? Do roughly 70 percent of the encounters with storms that have a PODEV of 70 percent result in deviations?)
   - Combine the probability of deviation maps with knowledge of terminal area routes to create a prototype decision support tool GUI for traffic managers. Show the terminal air routes along with the forecast weather and color-code the routes according to the forecast probability of deviation along those routes. Show the GUI to some operational traffic managers and solicit their comments.
4. Data from other airports should be analyzed to ascertain how penetration and deviation behavior may vary at different types of airports (hub vs. non-hub) and with different types of thunderstorms (line storms vs. air-mass storms).
5. The results of the present study should be briefed to organizations that are responsible for pilot training. This work could contribute to training materials that would enhance safety. Specifically, the material could review the current status of penetration and

deviation behavior near the airport and review other work that describes the dynamic nature of thunderstorms and wind shear. Taken together, the material would illustrate the fact that wind shear can "ramp up" in the few short minutes between consecutive aircraft penetrations of heavy rain and indicate that the absence of a wind shear alert or an unfavorable pilot report does not necessarily imply the absence of a hazard.

6. A specific study of missed and aborted approaches in the presence of thunderstorms should be undertaken. In the nine days of data examined for this study there were several instances when severe weather filled the nominal missed approach routes before runway operations ceased. When the first aircraft aborted its approach, several aircraft turned abruptly to the left or the right and penetrated storms containing very heavy precipitation, wind shear, and even microbursts. A detailed study of aborted approaches in the presence of thunderstorms might contribute to new training materials for pilots and controllers to use when making contingency plans near the airport in the presence of storms.

7. Additionally, special attention should be directed at those penetrations which seem to lead to subsequent regret. Regrettable penetrations could be identified using audio recordings of air-to-ground communications as well as analysis of flight track data.

# APPENDIX A
# A DESCRIPTION OF EACH DAY

The following pages describe each of the case days that were analyzed for this study. For each day there is:

- A description of the weather in the DFW region on that day
- A few comments about the impact of the weather on air traffic operations,
- Four snapshot images of weather and flight tracks
- The DFW TRACON traffic management logs ( for all days except April 24)

## Weather and Air Traffic Descriptions

The paragraphs describing the weather were taken from the MIT Lincoln Laboratory DFW ITWS prototype daily operations reports. The descriptions of air traffic operations were written by the authors of this report.

## WEATHER AND FLIGHT TRACK SNAPSHOTS

The weather in the images is the six-level ASR precipitation product. Red aircraft are DFW arrivals, blue aircraft are DAL arrivals, white aircraft are departures from either DFW or DAL. The aircraft tracks are shown for roughly a one minute period leading up to the time of the image.

## TRACON Traffic Management Logs

The TRACON traffic management logs demonstrate the dynamic nature of air traffic management. When reading the logs, keep the following in mind:

All times are listed in Greenwich Mean Time (GMT).

Arrivals are vectored over the following cornerposts:

| | | |
|---|---|---|
| UKW | BOWIE | northwest |
| JEN | GLEN ROSE | southwest |
| BYP | BONHAM | northeast |
| CQY | CEDAR CREEK | southeast |

The abbreviation “MIT” stands for miles-in-trail.

Entries that mention the number of routes north, south, east, and west are references to the number of available departure routes in that direction. There are nominally four routes available in each direction.

Entries listing the “rate” are referring to the airport acceptance rate. The clear-weather rate at DFW in 1997 was approximately 120 aircraft per hour. Figure A-1 shows the DFW TRACON and the standard jet arrival and departure fixes.

**Arrival Gates**
UKW – Bowie
BYP – Bonham
JEN – Glen Rose
CQY – Cedar Creek

**Departure Gates**
AMA – Amarillo
TCC – Tucumcari
LBB – Lubbock
ABI – Abilene

ACT – Waco
AUS – Austin
CLL – College Station
TNV – Navasota

LIT – Little Rock
TXK – Texarkana
ELD – El Dorado
EIC – Belcher

ADM – Ardmore
ZIM – Zemma
OKM – Okmulgee
MLC – McAlester

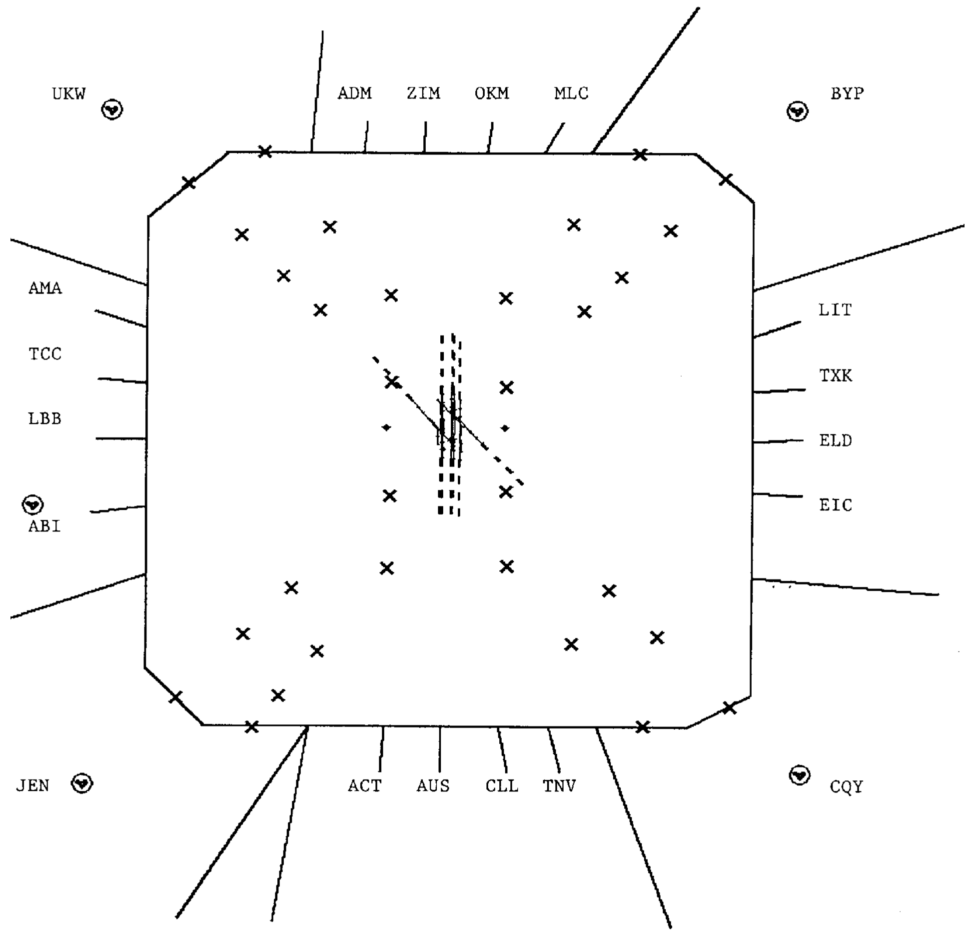
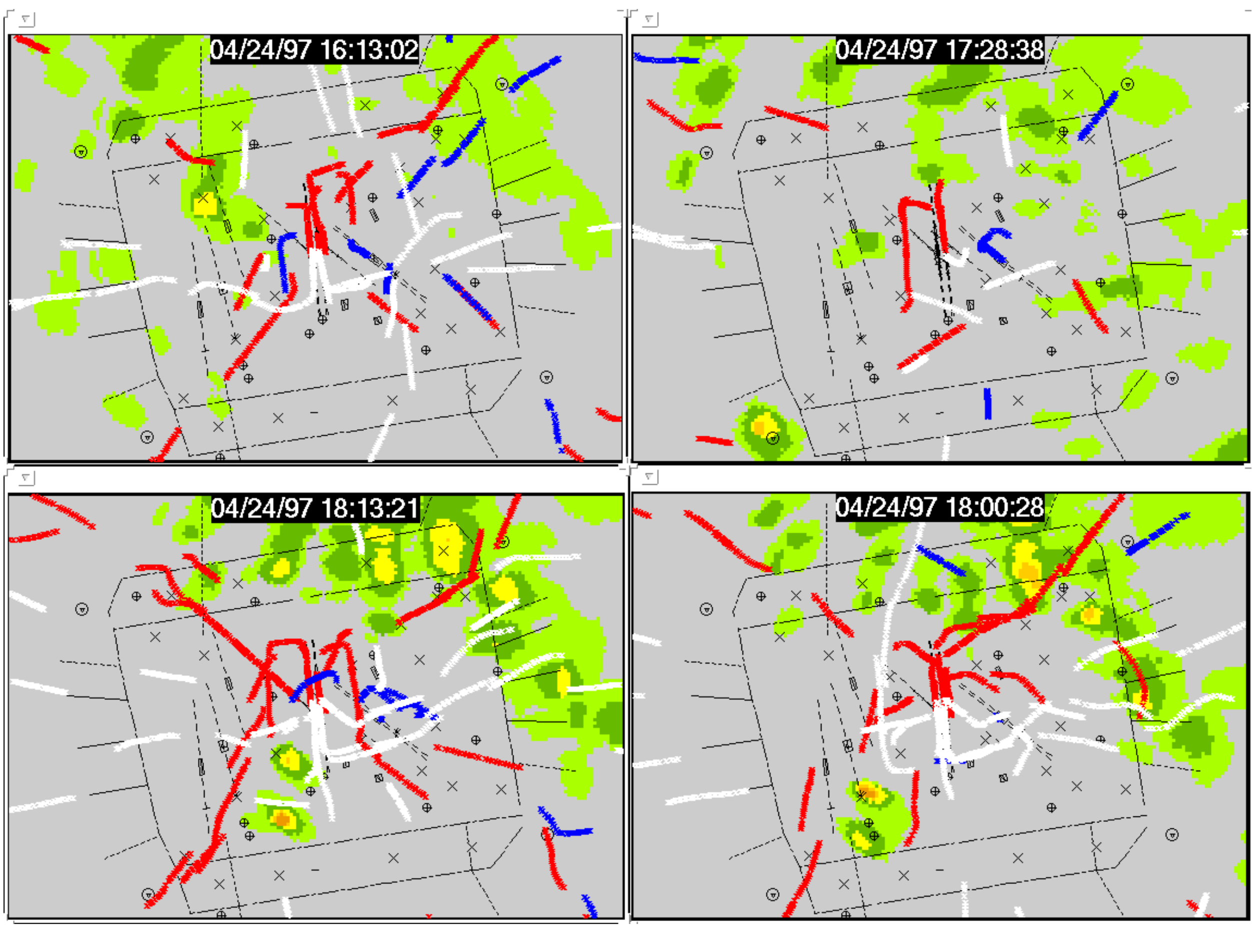



*Figure A-1. DFW TRACON with standard jet arrival and departure fixes.*

**April 24, 1997 1530 – 1900 UT – Weather and Air Traffic**

A low pressure center over New Mexico and an associated warm front set up an overrunning precipitation situation in the morning. Later, scattered level 3/4 storm cells developed and moved north east. Some level 4 cells developed near the SW gate and near the NE gate causing deviations in both regions. One of the cells that developed near the SW gate eventually moved over the airport, but remained on the southern end of the runways causing very little disruption to the traffic flow.

The airport remained in a south configuration throughout the period. There were many deviations as aircraft had enough room to maneuver around cells. Almost all the aircraft penetrated the level 1 and level 2 precipitation encountered along the arrival routes and several aircraft penetrated regions of level 3 precipitation. Traffic was variable, ranging from moderate to heavy.



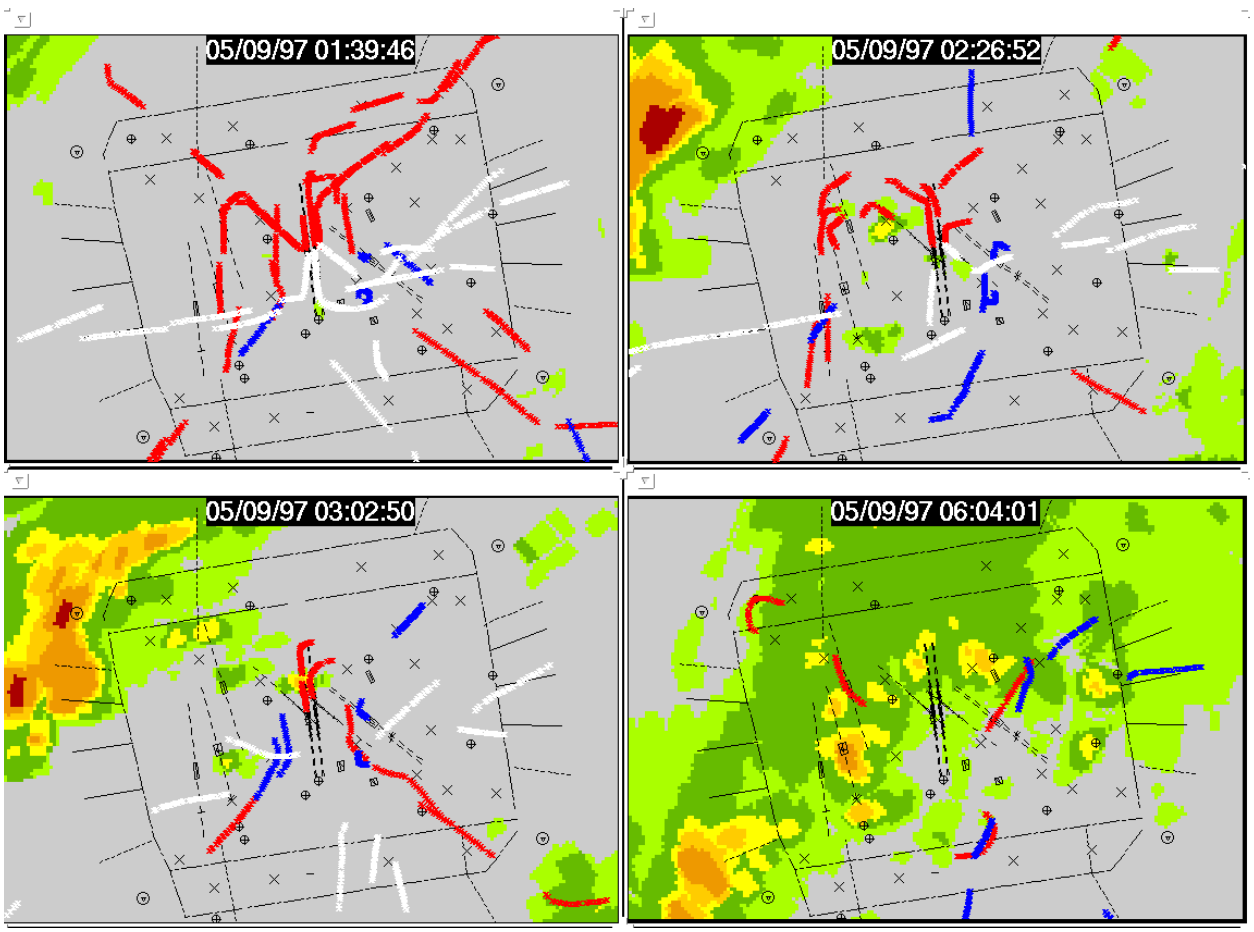

Traffic Management Logs – Not Available.

**May 9, 1997    0130 – 0800 UT – Weather and Air Traffic**

An east-west stationary front draped across northern Texas early in the day slowly pushed southward with a small reinforcement of cool air. This front sparked a wide area of precipitation that gradually moved through the TRACON.

A large area of precipitation with level 6 cells (at least one of which was tornadic) was present over the NW gate at the beginning of the period. In addition, several small level 2 and 3 cells developed near the airport. Higher intensity cells became more numerous to the west and north of the airport by 03:30 with movement to the east-northeast. Between 05:30 and 07:00, some level 4 and 5 cells formed and decayed within 15 miles of the airport.

The airport was in a south configuration at the beginning of the time period and switched to a north configuration around 06:00. The traffic on this day was generally light as this case began at 8:30 pm local time and ended at 3:00 am. Very few aircraft were able to use the NW gate due to the high intensity storms in the area, and the SW gate was shut down for about 3 ½ hours, but traffic was not impacted much by the storms in and around the airport. Many of the aircraft that encountered storms near the runways made penetrations (some even penetrated storms with microbursts).

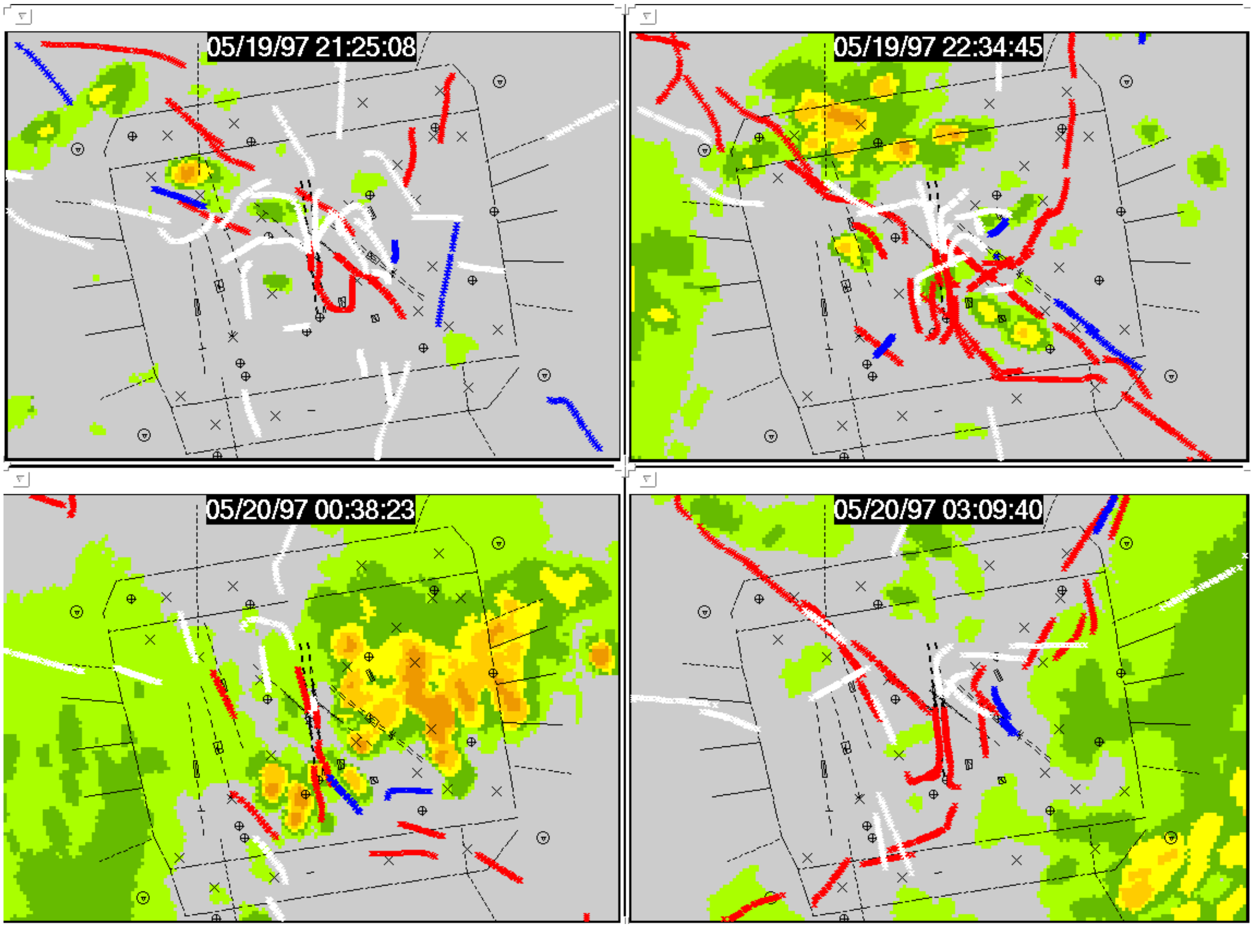


**Air Traffic Management Logs**

TIME REMARKS
1105 SOUTH FLOW.  DFW 120 RATE.
1233 DUAL CEDAR CREEK AT 1300 RUSH, 15 MIT.
1325 DUAL RT AT CEDAR CREEK CLSD.
1342 DFW +15 MIN DEP, ARTS EQUIP.
1346 DFW -15 MIN DLA'S.
1536 SKYDIVE TX HOT.  MASTY RTE STD, UKN 10 MIT PROPS/JETS.
1602 3 RTS NORTH, ZIM ON OKM.
1603 CP 1616, MTD, 7 MIN DLA'S.
1625 DFW +15.  TERM VOL.
1655 DFW 126 RATE/ALR 134.  NO DUALS.
1750 4 RTS NORTH, STD.
1807 DUAL RTE AT BONHAM FOR 1900 RUSH.
1855 CNCL SKYDIVE.
1901 DFW 120 RATE.
1920 CP 1930, MTD, 5 MIN DLAS.
2005 DUAL RE UKN 2045 RUSH, 10 MIT.
2120 DFW +15.
2133 DFW -15.
2139 3 RTES WEST, AMA ON TCC 10 MIT.
2143 DUAL RTE BONHAM 2230 RUSH, 10 MIT.
2313 DFW 126 RATE.
2323 1 RTE WEST OVR ABI.
2324 DUAL RTE BONHAM, 10 MIT 0000 RUSH.  DFW 120 RATE.
2333 CP 2357, MTD, 5 MIN DLAS.
2342 ONE RTE NORTH OVR MLC 10 MIT.  DFW 126 RATE.
0003 SWAP NORTH GATE EAST OVER LIT.
0012 10 MIT WEST.
0014 DFW 120 RATE AT 0030.
0025 DAL +15.
0034 DFW -15.
0040 STOP NORTH PROPS.  AWAITING SWAP.
0045 SWAP NORTH PROPS.  ZIP AND ADP WEST AND OKP AND MLP EAST.
0058 10MIT ON PROP SWAPS.
0111 SWAP NORTH PROPS EAST 10MIT.
0135 DFW +15.
0155 DFW +30.
0210 15MIT EASTGATE UNK WX.
0218 DFW --30, -15.
0220 10MIT EASTGATE.
0225 RADAR EASTGATE.
0258 SWAP WESTGATE SOUTH OVR ACT 10MIT, ACT/AUS RADAR.
0330 COMBINED @ ASIC POSITION.

**May 19, 1997 2030 – 0900 UT – Weather and Air Traffic**

High intensity, slow-moving, convective storms formed and covered a large region of the TRACON. Level 3, 4 and 5 storm cells impacted traffic in every arrival gate over the course of this day. Early in the period, storms covered the NW arrival routes, and new cells developed in and around the runways and the other three arrival regions causing much of the TRACON to be covered with precipitation for a long period of time. The storms were often closely spaced causing many aircraft to penetrate through tight gaps, penetrate moderate precipitation, or deviate around large regions of storms. Each of the arrival gates was closed for a period of time ranging from 15 minutes to 3 hours. By 03:30, the TRACON was free of storms, but convective initiation resumed around 05:00 with storms forming a line across the airport. These cells drifted generally eastward. The airport remained in a north configuration throughout the period, and traffic was moderate to heavy until near the end of the period when it became very light. Departure delays peaked at 90 minutes at 01:52. There were many penetrations and deviations on this day.




**Air Traffic Management Logs**

```
TIME  REMARKS
1045  SOUTH FLOW.
1105  DFW 120 RATE.
1217  DUAL RTE BYP 1300 RUSH, 10 MIT.
1220  TWO RTE WEST AMA/TCC ON LBB 10 MIT, ABI STANDARD.
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1230 SWAP ADM ZIM OKM WEST.  MCL ALONE 10 MIT.
1233 EXCLUDE OKM AND TUL LANDERS FROM SWAP.
1327 3 RTES WEST.  AMA AND SWAPS ON TCC, 10 MIT.
1339 DFW 126 RATE.
1343 15 MIT WEST GATE.
1349 10 MIT WEST GATE.
1403 STOP NORTH GATE DEPS.
1410 ZFW RLSD A TUL AND A OKC LANDER OFF DAL.
1411 DUAL RTE BYP 1415 RUSH, 10 MIT.
1415 DFW 120 RATE.
1416 DUAL RTE CLSD AFTER 4TH A/C ACCT WX.
1418 DFW 108 RATE ACCT LOSS OF 13R DUE WX.
1424 CP 1435, MTD, 7 MIN DLAS.
1429 SWAP NORTH GATE.  MLC AND OKM OVR LIT 10 MIT.  ADM AND ZIM WEST OVR TCC 10 MIT.
1450 4 RTES WEST.  10 MIT OVR AMA.  SWAPS OVR AMA.
1515 3 RTES WEST.  AMA AND SWAPS OVR TCC, 10 MIT.
1521 DFW 114 RATE.
1532 STOP NORTH GATE PROPS.
1537 SWAP NORTH PROPS.  GRABE OVR LIT AND ELECO OVR AMA.
1545 DFW 96 RATE (VSBY 1 1/4)
1555 4 RTES WEST, 10 MIT ON 283R.
1600 DFW 114 RATE.
1606 STOP BYP DFW ARR.
1607 DFW 96 RATE.
1608 RESUME DFW PROPS OVR BYP, 20 MIT.
1609 DFW PROP ARR 20 MIT ALL CORNERS.
1612 15 MIT EAST GATE.
1616 CP 1626, MTD, 7 MIN DLAS.
1621 ZFW UNABLE TO ASP METER, JETS 15 MIT FROM WEST, 20 MIT FROM EAST.
1633 DFW + 15.
1640 SWAP 092R OVR J87.
1644 10 MIT EAST GATE.
1653 DFW -15.
1700 SWAPS ON J87 10 MIT.
1706 NORMAL SPACING ON EAST GATE.
1710 DFW NORTH FLOW.
1732 DFW 114 RATE.
1746 1 RTE NORTH, ZIM OKM MLC OVR ADM 10 MIT.  ADM STILL SWAP WEST.
1751 INTERNAL REST.  1 RTE EAST.
1759 RESUME BYP ARR.
1805 ZIM OKM MLC OVER OKM, 10 MIT.
1809 NORTH PROPS NORMAL.
1816 2 RTES EAST, LIT OVR TEK AND ELD ALONE.
1818 2 RTES NORTH.  ADM 10 MIT AND ZIM AND MLC OVR OKM 10 MIT.  CNL ADM SWAP.
1822 DFW +15 DEPT DLAS.
1835 DUAL RTE CQY 1915 RUSH.
1837 1 RTE EAST 10 MIT.  CNL INTERNAL EAST REST.
1844 4 RTS NORTH.
1903 DFW -15 MIN DLA'S.
1907 CP 1926, MTD, 4 MIN DLA'S.

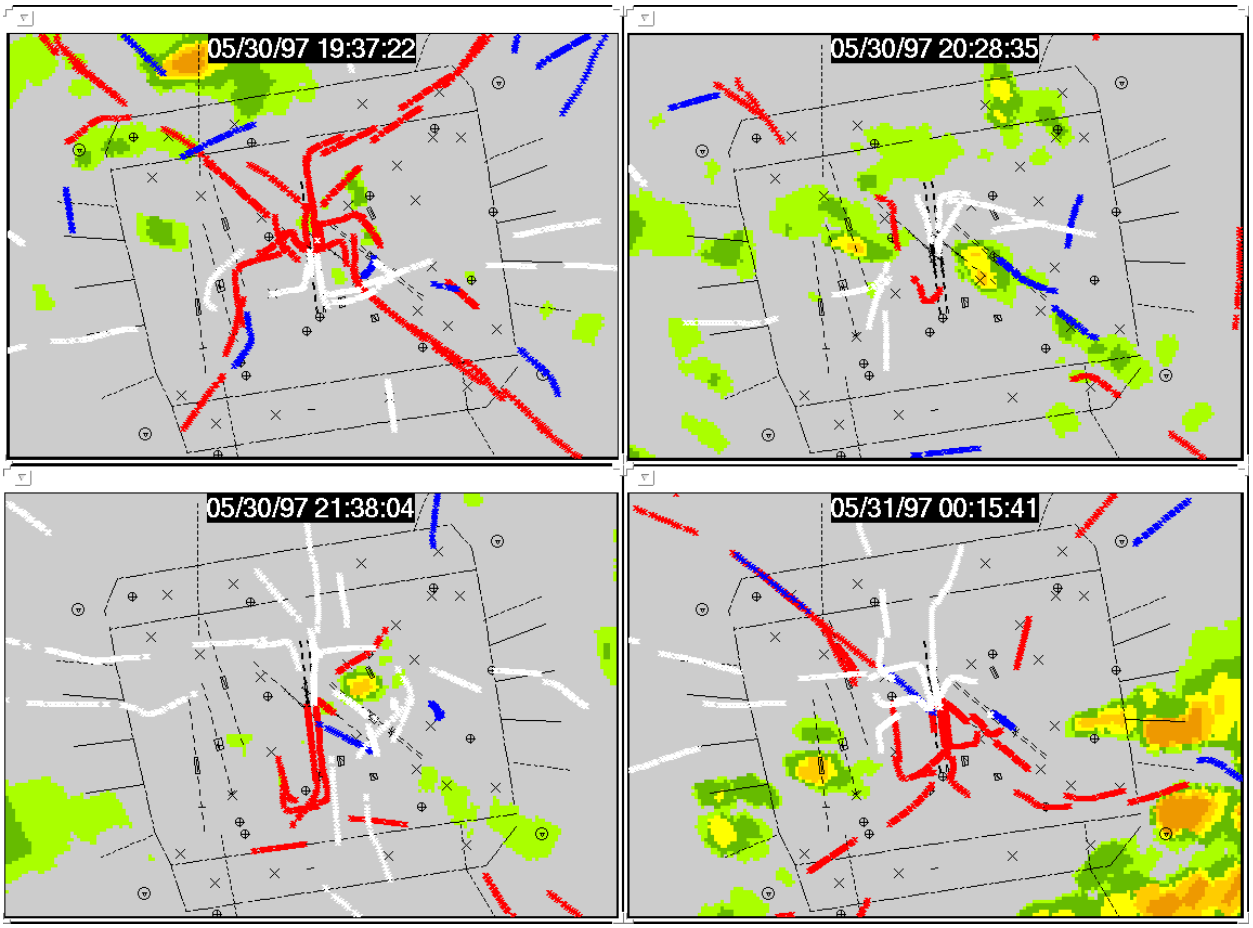
1925 GRABE OUT ELECO UNTIL 2000.
1945 3 RTS EAST, 10 MIT, ETC STILL SWAPPED SOUTH, 10 MIT.
2031 2 RTES WEST, ABI, TCC 0/LBB.
2050 2 RTS WEST ON PROPS, ABP AND GTP ON TCP.
2056 1 RTE WEST ON 283R, JETS PROPS.
2100 1 RT WEST OVR 283R, 10 MIT.
2113 DFW +15 DLAS.
2138 DFW +30 MIN DLA'S, WX.
2140 15 MIT OVER UKN, PROPS AND JETS, WX.
2147 DFW 108 RATE, WX DEV.
2205 WST JET RTS ON 273R.
2207 2 RTS NORTH, ADM AND ZIM ON OKM, 10 MIT.
2207 DFW -30 AND -15 MIN DLA'S.
2212 CP 2228, MTD, 5 MIN DLA'S.
2222 10 MIT ON UKN JETS.
2230 STOP WST JET AND PROP DEP.
2235 ONE RT NORTH, 10 MIT.
2243 STOP UKN/DFW/DAL JETS.
2245 DFW SEND JETS LEFT TURN ONLY.
2249 2 RTS EAST; LIT/TKK OVR ELD. CNCL EIC SWAP.
2250 DAL +15. WX
2254 DFW +15.
2304 RESUME UKN JETS 15 MIT.
2305 DAL +30.
2309 EASTBOUND JETS STOPPED WX.
2313 DFW +30.
2319 WEST PROPS 1 RT OVR AMP 10 MIT.
2320 DAL +45.
2331 DFW +45.
2333 CNCL MTD. ALL PROPS 10 MIT; UKN/BYP JETS 15 MIT. JEN/CQY STD.
2334 STOP BYP/DFW.
2335 DAL +60.
2346 DFW +60.
2350 DAL -60, -45, -30, -15.
2358 STOP ALL DFW ARRs. MD/WS ALERTS ALL RWYS. ACFT REFUSE APCHS.
2359 SWAP TEK LIT NORTH, EIC ELD SOUTH, ONE RT NORTH, 10 MIT.
0018 DFW -60.
0021 RSM DFW ARRs AT UKN, JEN AND CQY 20 MIT PROPS/20 MIT JETS. USING RWY 36L ONLY DUE TO WINDSHEAR/OCCN MB ALERT.
0030 HOLD ALL DAL ARR, WX.
0030 SWAP EAST PROPS NORTH.
0033 HOLD ALL DFW ARR.
0052 RESUME DAL, ARR, 10 MIT AT CQY.
0054 1 ARR TO DFW AT ALL CP.
0114 RESUME DFW ARR 20 MIT ALL CP JETS AND PROPS, HOLD BYP PROPS.
0117 DFW + 60 MIN DEP DLA'S, WX.
0118 IAP ON.
0127 3 RTS WEST. LBB OVR ABI. ALL 10 MIT.
0133 AMND 3 WEST RTE. LBB OVR TCC.
0137 DFW +75.
0140 IAP OFF.

0153 DFW ARR BYP 5 MIT, JEN 10 MIT, UKN 5 MIT, CQY 20 MIT, PROP AND JET.
0152 DFW +90.
0157 2 RTS NORTH 10 MIT
0158 DFW 96 RATE. STD SEP ALL CPs.
0222 CNCL LIT/TKK JET SWAP. CNCL EAST PROP SWAP. 1 RT EAST OVR LIT 10 MIT.
0224 LCL RSTN: 1 RT NORTH 10 MIT.
0225 RWY 31R AVAILABLE UFA.
0226 2 RTS WEST. AMA/LBB OVR TCC. 10 MIT.
0228 START MED ASAP. 12 MIN DLA.
0235 LIT/TKK 15 MIT.
0245 UNABLE TO METER AT BYP, WX, 15 MIT SAME TYPE.
0252 DFW -90.
0257 DFW -75, -60.
0258 CNCL ELD/EIC SWAP. 1 RT EAST OVR LIT 15 MIT.
0259 DFW -45, -30.
0301 DFW -15.
0327 STOP ALL UKN TFC. STOP BYP/DFW ARRS. TERM VOL.
0332 RSM BYP AND UKN 15 MIT LIKE TYPES.
0352 RSM STD SPACE ALL ARRS.
0400 ALL DEP RTS 10 MIT.
0404 4 RTS WEST STD. ALL OTHERS 10 MIT.
0413 2 RTS SOUTH; AUS OVR ACT, CLL OVR TNV. 10 MIT BOTH.
0440 COMB AT AS3.

**May 30, 1997 1845 - 0200 UT – Weather and Air Traffic**

Late in the day, a cold front pushed through the Dallas area bringing heavy rain and thunderstorms. Early in the period, some storms moved into the TRACON from the northwest and moved southeast, but for the most part, level 3,4, and 5 storms formed within the TRACON. Though some storms did cross the airport, there was little impact on the traffic flow near the airport. Most of the deviations occurred around storms at the SW, SE, and NE arrival gates and routes. A line of level 5 and 6 storms with hail formed on the eastern edge of the TRACON and moved south.

The airport was in a south configuration until 20:18 when it was switched to a north configuration. The traffic on this day was moderate to heavy. There were numerous penetrations and deviations.




**Air Traffic Management Logs**

```
TIME  REMARKS
1100  SOUTH FLOW.  DFW 84 RATE. JEN 10 MIT.
1152  MEM 15 MIT.  ENRT TSTM.
1223  1 RTE WEST OVR ABI, 10 MIT.
1246  DFW 78 RATE; WX DEVS.
1316  SWAPS WEST GAT, AMA N OVR ADM, TCC, LBB, ABI SOUTH.
1324  PROPS 1 RTE WEST OVR 283 10 MIT.
```

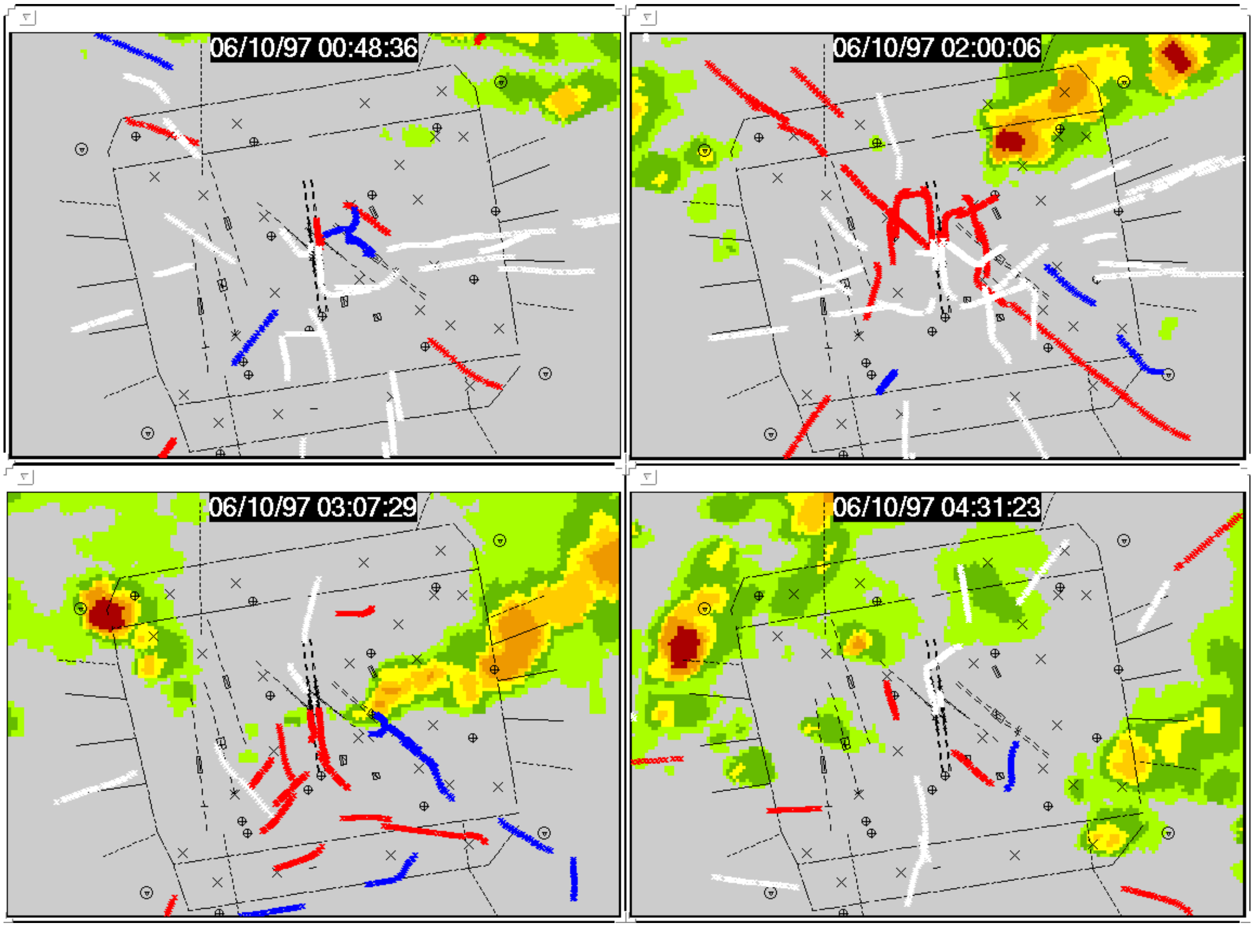
1325 1 RTE WEST OVR 283 10 MIT, CNCL AMA SWAP.
1330 DFW IAP ON.
1345 DFW +15. WX/SWAPS.
1348 20 MIT OVR JEN.
1350 DFW -15 MIN DLA's.
1412 CNCL WEST SWAPS, USE 2 RTE'S WEST TCC OVR 283, LBB/ABI OVR 273.
1438 CQY JETS 10 MIT.
1442 PROPS 4 RTE'S WEST, NORMAL SPACING.
1451 3 RTE'S WEST ABI OVR LBB 10 MIT, NORMAL SPACING OVR TCC/AMA.
1506 CNCL LAX SCDT. 4 RTS WEST SLD. CNCL CQY RSTN.
1537 DFW 120 RATE. NO DUALS.
1612 DFW 126 RATE.
1618 3 RTE'S SOUTH INV OVR CLL.
1638 STOP CQY/DFW, AND JEN/DFW TFC. WX: M9BKN
1643 RSM MTD AT 96 RATE.
1645 ZFW ADVSD UNABLE TO METER.
1730 DFW 120 RATE.
1811 4 RTS EAST, 10 MIT.
1822 SWAP ADM WEST OVR AMA, 3 RTS WEST, STD.
1833 4 RTE'S SOUTH, NORMAL SPACING.
1841 DFW 126 RATE, NO DUAL.
1900 ONE RTE NORTH ON TUL 10 MIT, THREE RTES EAST 072 ON 082, EAST GATE 15 MIT.
1920 THREE RTS WEST AMA ON TCC 10 MIT.
1950 TWO RTES WEST 273 ON 262 10 MIT, STOP NORTH GATE. DFW 96 RATE.
1954 DFW +15.
2004 SWAP NORTH GATE WEST OVR LBB, 20 MIT.
2005 2 RTES WEST, SWAPS ON 262R, 20 MIT AND ALL WEST RTES OVR ABI STD.
2006 30 MIT STL.
2014 2 RTES EAST, LIT 15 MIT AND TKK AND EIC OVR ELD 10 MIT.
2018 DFW + 30. DFW NORTH.
2026 DFW + 45.
2030 DAL +15.
2040 TWO RTES NORTH ZIM ON ADM, MLC ON OKM, 10 MIT.
2045 TWO RTE WEST AMA TCC LBB 10 MIT. ABI. TWO RTES SOUTH TNV CLL ON AUS 10 MIT. ACT
2049 CP 2058, MTD, 5 MIN DLAS.
2050 DAL +30 2045.
2051 DFW -60, 45, 30.
2058 TWO RTES WEST LBB TCC ON AMA 10 MIT. ABI.
2100 STOP SOUTH GATE.
2110 TWO RTES SOUTH TNV CLL ON AUS 10 MIT. ACT.
2113 TWO RTE EAST LIT TKK ON ELD 10 MIT, EIC.
2125 DFW +30.
2128 TWO RTES WEST, TCC ON AMA 10 MIT, ABI LBB ON TCC 10 MIT.
2132 DAL +15 @ 2125.
2138 2 RTES SOUTH 10 MIT. ACT OVR AUS AND TNV OVR CLL.
2142 2 RTES SOUTH 10 MIT. AUS AND ACT ON 164R AND ALL OVR TNV.
2151 DFW 108 RATE.
2155 THREE RTES WEST ABI/LBB 10MIT.
2203 DFW -15.
2203 3 RTES NORTH, MLC OVR OKM, 10 MIT ALL RTES.

2204 DAL -15.
2209 FOUR RTES NORTH STANDARD.
2216 CP 2230, MTD, 5 MIN DLAS.
2225 GRABE OVR ELECO TIL 0030.
2231 1 RTE SOUTH 10 MIT OVR TNV.
2233 DFW 114 RATE.
2240 ONE RTE EAST 092 10 MIT.
2252 DFW +15.
2253 4 RTES WEST, SRD.
2305 DFW -15.
2316 SWAP EASTGATE LIT/TKK/ELD OVR MLC AND EIC OVR TNV 10MIT ALL SWAPS.
2318 10MIT OVR MLC.
2320 MEM NORMAL.
2330 GRABE OVR BELCO/0200Z.
2334 ONE RTE EAST 15MIT RADAR VECTORS PROPS.
2340 CP 2355 MTD 6 MIN DLAS.
2354 DFW + 15.
2356 STOP SOUTH JETS.
0005 ZFW STOPPED CQY ARR.  CNCL METERING.
0110 THREE RTES WEST LBB ON ABI 10 MIT.  SWAP SOUTH GATE AND 092R WEST.
0022 MOVE SWAPS WEST AND ABI OVR LBB.
0028 DAL +15 0021Z.  262R 15 MIT.
0036 SWAP SOUTH WEST OVR ABI.
0041 DFW +30.
0059 THREE RTES NORTH MLC OVR OKM.
0100 OKM 10 MIT.
0115 DFW + 45.
0132 DFW - 45.
0138 FOUR WEST STANDARD.  SWAPS OVR ABI 10 MIT.
0145 DAL +45.
0146 DAL -45 & -30.
0148 DFW +45.
0158 FOUR RTES NORTH STANDARD.  SWAPS 10 MIT.
0200 DFW - 45.
0220 DAL + 45.
0225 WEST GATE 10 MIT.
0227 DAL -45.
0240 DFW + 45.
0310 WEST GATE 283R 273R STANDARD, ABI ON LBB 10 MIT.  SWAPS ON ABI 10 MIT.
315 DAL-30, -15.
0330 COMBINED AT ASIC.

**June 10, 19970030 - 0730 UT – Weather and Air Traffic**

A cold front pushed down from Oklahoma bringing severe thunderstorms into north Texas. Level 4, 5, and 6 storms moved into the TRACON from the NW, and new storms formed inside the TRACON along the southwestern edge of this convection and moved to the southeast. Storm cells impacted each of the arrival gates and the airport region at times shutting down the NE, NW, and SW gates for periods of time ranging from ½ hour to 2 hours. The precipitation was not widespread over the TRACON at all times.

The airport changed from a south to a north configuration around 02:30. The traffic on this day was moderate, becoming light near the end of the period.




**Air Traffic Management Logs**

```
TIME  REMARKS
1115  NORTH FLOW.  DFW 114 RATE.
1130  2 RTS EAST, LIT AND TKK ON ELD, 10 MIT BOTH.
1140  ONE RT NORTH OVER ADM.
1215  SOUTH FLOW.
1225  THREE RTES EAST, LIT ON TKK 10 MIT.  ELD 10 MIT.  EIC STANDARD.
1234  DFW 96 RATE.
1236  2 RTS NORTH, MLC AND OKM ON ZIM.
1256  DFW 108 RATE.
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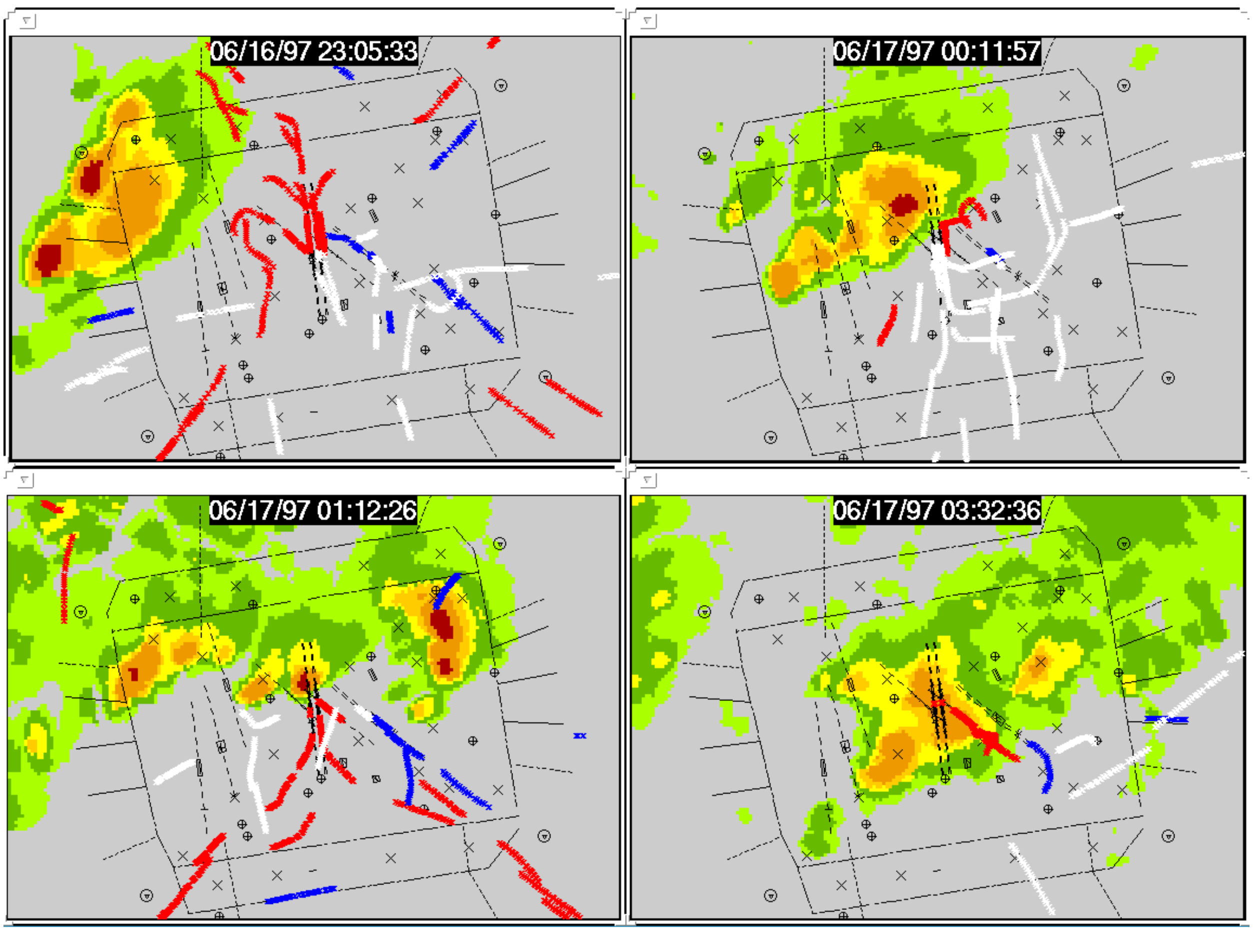
1342 DFW 114 RATE.  ALR 126.
1420 2 A/C UKN DUAL RTE.
1438 IAP ON.
1445 DFW 120 RATE.
1600 CP 1613 MTD 7 MIN DLAS.  IAP OFF.
1613 DUAL RTE UKN, 5 A/C MAX 10 MIT.
1629 4 RTES NORTH, STD.
1648 3 RTES WEST, TCC ON LBB.
1706 4 RTES EAST, 10 MIT ON TKK AND LI
1717 DUAL RTS AT UKN, 10 MIT.
1737 3 RTS EAST, ELD ON EIC, 10 MIT AND TKK AND EIC.
1820 DUAL RTE CLOSED.  DUAL RTE OVR BYP.
1854 WEST GATE NORMAL.
1858 2 RTS EAST, TKK O/LIT 10 MIT, ELD O/RIC 10 MIT.
1920 BYP RTE UNUSABLE, ARRIVALS ON JONES RTE.
1950 DFW +15 DEPT DLAS.
2000 BYP RTE OK.
2002 DFW -15 DLAS.
2005 DUAL RTE OVR UKN, 10 MIT.
2838 3 RTS WEST; AMA OVR TCC.
2058 4 RTS WEST.
2105 UKN DUAL CLSD AFTER AAL2034.
2115 DUAL RTE AT BYP 2215 RUSH, 10 MIT.
2122 BISHOP AREA ACTIVE.
2137 IAH NORMAL SPACING.
2200 SWAP TKK & LIT JETS NORTH OVR MLC, 10 MIT.
2216 3 RTS NORTH ADM O/ZIM.
2224 BYP TRAFFIC ON JONES RTE FOR WX.
2231 2 RTS NORTH ADM AND ZIM O/ OKM NORMAL SPACING.
2253 DFW +15.  NBND RSTNS/SWAPS.
2254 GRABE PROPS MAINT AT/BLO 100.
2300 1 RT NORTH, 10 MIT.  STOP NO. DEPS.
2303 RSM N. DEPS.
2312 CNCL SWAP.  3 RTS EAST, ELD OVR EIC, ALL 10 MIT.
2313 STOP NORTH DEPS.
2316 DFW +30, ENRT WX. LIT AND TKK RTS 15 MIT.
2331 DFW -30, -15.
2339 SWAP AUM/ZIM WEST OVR AMA 15 MIT, SWAP OKM/MLC EAST OVR LIT 15 MIT.
2342 2 RTS EAST.  LIT/TKK/SWAPS OVR 082R 10 MIT; ELD OVR EIC 10 MIT.
2344 082R 15 MIT.  BISHOP AREA CLOSED.
2358 STOP N PROPS.  FRISCO REFUSED TO ACCEPT PROPS.
0003 2 PROP RTS EAST; LIP/TKP OVR ELP.  SWAP GRABE PROPS OVR ELP.
0020 082R 10 MIT.
0034 ZIP/ADP 40, 20 MIT OVR UKN APVD BY BPR.
0205 CNCL SWAP.  1 RT NORTH OVR ADM 10 MIT.
0224 NORTH FLOW.
0240 1 RTE WEST O/ABI.  2 RTS EAST LIT & TEK 0/ ELD, 10 MIT.
0245 COMBINED WITH ASIC.

**June 16, 19972130 - 0830 UT – Weather and Air Traffic**

An upper level low pressure area moved through the extremely unstable atmosphere in north Texas and Oklahoma in the evening. The low triggered numerous level 6 cells with lightning, hail, and wind shear of up to 65 knots. Large regions of precipitation moved into the TRACON from the west and headed east-northeast to impact the airport. Each of the arrival gates was closed for a period of time ranging from ½ hour to 3 hours, and the airport experienced several "waves" of level 5 precipitation accompanied by lightning, wind shear, gust fronts and microbursts. On several occasions, the airport was closed briefly when these strong storms moved over the area. During much of the day, the precipitation covered about half of the TRACON area.

The airport was in a south configuration at 21:30, but changed to a north configuration around 00:50. The traffic on this day was moderate, but became heavy at times when one or more of the arrival routes became unusable or when the airport reopened after being closed briefly. The weather on this day had a significant impact on the air traffic.




**Air Traffic Management Logs**

```
TIME  REMARKS
1130  SOUTH FLOW, 114 RATE, ALR 124.
1152  ONE RTE OVR ADM 15 MIT.
1250  TWO RTES NORTH ADM.  MLC/ZIM ON OKM 10 MIT.  IAP ON.
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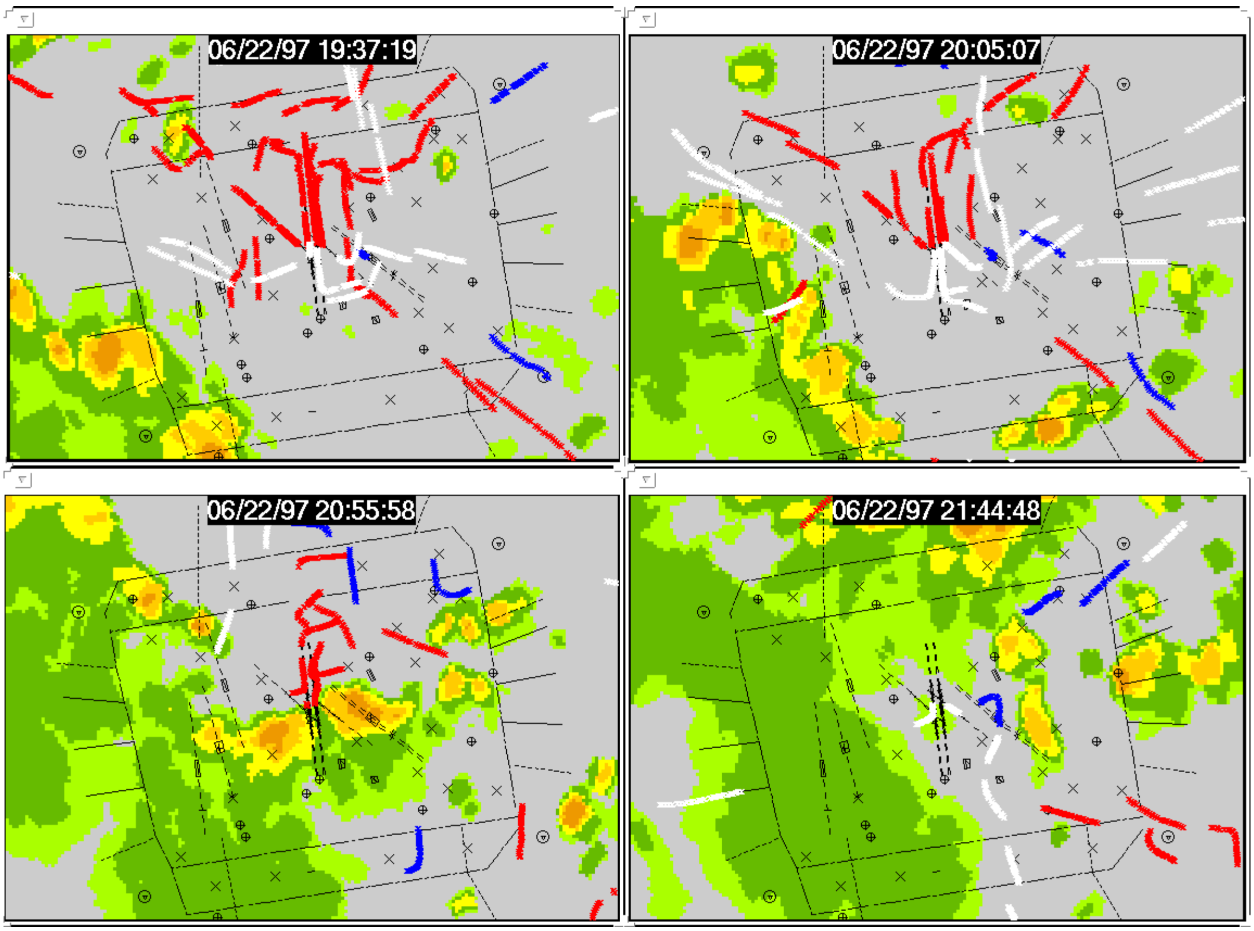
1305 SAT LNDRS OVR ACT.
1320 SAT STANDARD.
1328 IAP OFF.
1344 DFW 120 RATE. ALR 132.
1400 DFW 114 RATE, DUAL RTE OVR UKN 10 MIT. ALR 132.
1447 NORTH GATE STANDARD.
1600 CP 1624 MTD 4 MIN DLAS.
1745 DUAL RTE OVR UKN 10 MIT.
1824 DUAL RTE CLOSED.
1830 DUAL RTE OVR BYP, 10 MIT.
1859 CP 1918, MTD, 7 MIN DLAS.
1909 3 RTS EAST, TKK O/ LIT.
1925 STOP MTD.
2013 3 RTS WEST, LBB O/TCC, 10MIT.
2021 2 RTS WEST, TCC & LBB O/ABI, 10 MIT.
2028 GND STO DCA UPDATE 2200.
2037 4 RTS EAST.
2047 GND STOP CVG. UPDATE 2145.
2112 EXTND DCA UPDATE 2300.
2123 DUAL RT AT BYP AFTER 2200.
2124 GND STOP ATL. UPDATE 2230.
2126 RSM DCA TFC.
2128 EXTND CVG UPDATE 2245.
2130 DFW +15. WX: ENRT.
2147 RLS CVG.
2148 DFW -15. DEN LTFC TMU-RRT OVR ZIM.
2157 GND STOP STL. UPDATE 2230.
2210 AMA 10 MIT. RLS ATL.
2212 1 RT WEST OVR ABI, 10 MIT.
2224 4 RTS NORTH, NORMAL SPACING.
2229 RLS ATL.
2236 3 RTS NORTH; OKM OVR ZIM, STD.
2239 ALL UKN ARRS OVR GREGS 10 MIT LIKE TYPES. WX DEVS.
2250 UKN ARRS INBND OVR BLECO 10 MIT LIKE TYPES. BLECO PROPS @ 40.
2304 NBND DFW JETS LEFT TURN OUT.
2309 SWAP WEST JETS SOUTH OVR ACT, 15 MIT ON SWAPS..
2322 1 RTE NORTH O/OKM.
2332 GND STOP ATL. UPDATE 2230.
2334 DFW 84 RATE, WX NORTH WEST OF FIELD.
2339 15 MIT JEN, 10 MIT CQY, 10 MIT BYP.
2342 STOP ARRIVALS TO DFW.
2352 MOVE ACT O/AUS & SWAPS O/ACT 15 MIT.
2358 RLS ATL.
0020 DFW NORTH FLOW
0015 DFW +15. WX:ARPT.
0030 DFW +30.
0045 DFW +45
0050 RLS ARRIVALS FROM UKW & CQY, 20 MIT.
0100 DFW +60
0106 10 MIT ON JETS & PROPS.
0111 DUAL RTE OVR CQY, 10 MIT.
0115 DFW +75.

0130 DFW +90.
0145 DFW +105.
0157 SWAP ADM SOUTH, SWAP NORTH GATE EAST, 1 RTE OVR EIC.
0200 DFW +120.
0215 DFW +165.
0223 10 MIT ON 185R.
0230 DFW +150.
0252 DFW +165.
0306 DFW +180.
0321 STOP DFW ARRS.  WX:ARPT.
0354 DFW +210.
0424 DFW +240.
0445 COB.

**June 22, 19971845 - 2245 UT – Weather and Air Traffic**

A region of level 4 and 5 cells moved into the TRACON from the southwest and moved northeast impacting the SW arrival gate and eventually the airport. Numerous other level 3,4, and 5 storm cell storms popped up around each of the other three arrival gates and moved north causing deviations on all the arrival routes. Around 21:00 storms containing microbursts closed the airport for about 30 minutes causing all incoming aircraft to turn around and leave the TRACON. Many of the aircraft circled just outside the TRACON waiting for the weather to clear, and some flew to alternate airports.

The airport was in a south configuration for the entire period and the traffic on this day was moderate. There were numerous penetrations and deviations on this day.




**Air Traffic Management Logs**

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TIME  REMARKS
1130  SOUTH FLOW DFW 90 RATE PTOL 50 ALR 96, IAP ON, TRW IFR.
1144  NEGATIVE CONTACT ITWS.
1202  ONE RTE EAST OVR ELD 10MIT.
1209  IAP OFF.
1211  ONE RTE EAST OVR TKK 10MIT.
1215  ITWS ACTIVE.
1234  BYP RTE 10MIT HEADING 270 OUT OF KARLA.
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1238 10MIT PROP OVR SOUSA WESTBOUND, JETS 15MIT CQY.
1245 STOP BYP ARRIVALS.
1249 STOP JET ARRIVALS CQY.
1318 ONE RTE NORTH OVR MLC 10MIT.
1325 FOUR RTE EAST RADAR.
1343 DFW +15.
1349 DFW STOPPED ALL ARRIVALS MULTIPLE GO-AROUNDS.
1359 DFW +30.
1402 FOURS RTES EAST 10MIT.
1405 RESUME ARRIVAL WITH TEST OVR BYP & CQY.
1413 CEDARL CREEK ARRIVALS 10MIT.
1422 STOP CQY. TESTING UKW RTE.
1428 DFW +45.
1429 UKW ARRIVALS 10MIT.
1431 BYP ARRIVALS 15MIT.
1442 DFW -45.
1444 CQY ARRIVALS 10MIT.
1450 DFW -30.
1454 BYP RTE 10MIT.
1459 DFW -15.
1500 NORMAL SPACING OVR BYP & CQY.
1503 DFW 114 RATE.
1514 TWP RTES WEST ABI/LBB & AMA/TCC 10MIT.
1515 FOUR RTE EAST RADAR.
1521 THREE RTES NORTH ADM OVR ZIM RADAR.
1523 TWO RTES NORTH OKM/MLC.
1543 THREE RTES NORTH ADM/ZIM RADAR.
1554 ONE RTE WEST OVR AMA 10MIT.
1559 FOUR RTES NORTH RADAR.
1600 CP 1625 MTD 7'DLA.
1629 TWO RTES WEST TCC/AMA & ABI & LBB OVR 273R 10MIT WESTGATE.
1701 ONE RTE WEST OVR AMA 10MIT.
1748 ONE RTE WEST OVR TCC 10MIT.
1752 STOP WEST DEPARTURES STANDBY FOR SWAP.
1757 THREE RTES SOUTH ACT/AUS RADAR.
1758 SWAP WESTGATE NORTH OVER ADM 15MIT.
1814 DFW +15.
1826 CXL SWAP, 1 RTE WEST ON 262R, 10 MIT. 1 RTE SOUTH ON 164R, 10 MIT. 10 MIT ON 062R & 072R.
1832 DUAL RTE OVR BYP, 10 MIT, 6 AIRCRAFT.
1836 DFW +30.
1840 DFW -30.
1843 DFW -15.
1850 1 RTE SOUTH, 15 MIT.
1906 GND STOP JFK, EWR, LGA, & BOS. UPDATE 2030.
1912 STOP SOUTH GATE.
1928 10 MIT ON 092R.
1930 SWAP SOUTH GATE, 185R & 174R WEST & 164R & 154R EAST. 4 RTS WEST 10MIT.
1950 WEST GATE ON 283 R.
2008 STOP WEST GATE, AWAINTING SWAP.
2010 3 RTES EAST, LIT ON TXK, 10MIT, 10 MIT ALSO OVR EIC.

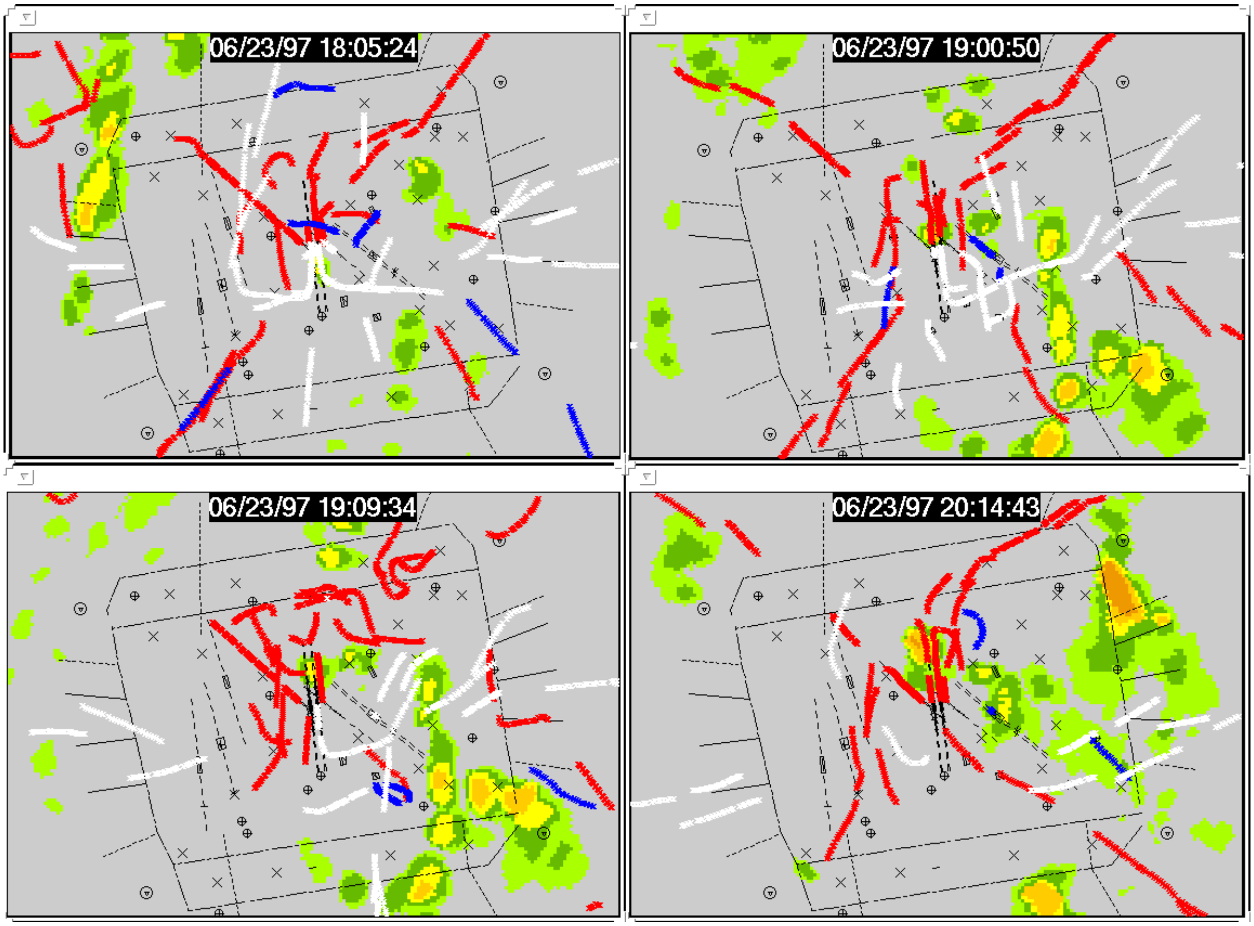
2016 SWAP WEST GATE OVR ADM. 15 MIT OVR ADM. SWAP SOUTH GATE OVR EIC, 10 MIT.
2017 2 RTES EAST, LIT OVR TEK AND EIC/SWAPS OVR ELD, 10 MIT BOTH.
2020 1 RTE EAST OVR TXK, 10 MIT. SWAP PROPS SAME AS JETS.
2023 RLS JFK, EWR, LGA. CONTINUE BOS STOP.
2030 RLS BOS.
2034 DFW 96 RATE/ WX DEVIATIONS. ATCSCC ADVISED.
2040 STOP DFW ARRIVAL AFTER 2050 CP TIME.
2045 STOP ALL CP ARRS.
2047 STOP DEPTS.
2115 DFW + 15 DEPT DLAS.
2120 DAL +15 @ 2055 AND +30 @ 2110.
2123 RLS 1 SOUTH AND 1 WEST TEST DEPT.
2130 DFW +30
2140 DFW +45 & +60.
2141 2 RTS SOUTH AUS & ACT 0/ 164 & CLL O/TNV.
2143 STOP LGA.
2153 1 RTE WEST OVR TCC, 10 MIT.
2156 DFW +75.
2159 DFW JEN ARRS NRML, JETS AND PROPS.
2204 RESUME CQY ARRS. JETS STD, PROPS 10 MIT.
2210 DFW +90.
2214 WEST PROPS NORMAL.
2219 1 RTE SOUTH OVR TNV, 10 MIT.
2225 DFW +105.
2234 DFW +120.
2242 SWAP ELD/EIC SOUTH OVR AUS, SWAP ADM/ZIM OVR TCC, 10 MIT.
2255 DFW +135.
2302 ALL ARRIVAL RTES OPEN FOR DFW. DFW 108 RATE.
2307 3 RTES SOUTH, TNV AND SWAPS OVR CLL. 10 MIT BETWEEN SWAPS.
2312 1 PROP RTE NORTH OVR ADP, 15 MIT.
2320 SWAP NORTH GATE WEST.
2325 DFW -135.
2331 SWAP EAST GATE SOUTH, 10 MIT.
2334 30 MIT WEST SWAPS.
2338 ABI/LBB TFC ON 262R.
2339 5 EAST PROPS RELEASED.
2345 DFW -120.
2352 DFW -105.
0000 CP 0015, MTD, 6 MIN. DFW -90.
0008 STOP NORTH PROPS.
0012 DFW -75.
0020 EAST PROP DEPS NORMAL. DFW -60.
0023 3 RTES EAST, LIT OVR TXK.
0030 BIC 0/BLD.
0036 DFW 84 RATE/ ATCSCC NOTIFIED ACCT TS.
0038 RLS LGA.
0049 DFW +60.
0053 DFW +75.
0105 STOP DFW ARR ACCT TS.
0106 1 RTE WEST OVR LBB, 10 MIT. SWAPS 30 MIT.
0116 STOP WEST GATE.

0120 1 PROP RTE NORTH.
0122 RESUME ARR UKN DFW 10 MIT LTFC.
0126 DFW +90.
0128 STOP EAST SAT TFC.
0138 DFW +105.
0046 STOP UKN DFW ARRS.
0048 DFW +120.
0050 RESUME EAST SAT ARRS.
0152 RESUME UKN DFW ARRS, 10 MIT LTFC.
0205 DFW +135.
0207 3 RTES NORTH, ZIM OVR OKM.
0210 RESUME JEN ARRS DFW, 10 MIT LTFC.
0211 3 RTES EAST, LIT OVR TXK.
0221 SWAP WEST GATE OVR ADM.
0235 CLOSE JEN, OPEN BYP 10 MIT LTFC AND OPEN CQY 15 MIT LTFC.
0241 DAL -15.
0242 4 RTES EAST AND 4 RTES SOUTH STD.
0243 DFW 66 RATE. GRIDLOCK ON WEST SIDE.
0244 SWAP ABI OVR ACT, 15 MIT SWAPS.
0300 DFW +150.
0320 DFW +165.
0345 ADM OVR ZIM. SWAPS OVR ADM. NORTH PROPS NORMAL.
0345 DFW +180.
0353 DFW OUT OF DLAS (-15)
0400 ARR RATE REMAINS 66. 13R/17L CLOSED.
0445 COMBINED ASIC.

**June 23, 19971600 - 2200 UT – Weather and Air Traffic**

The airmass over North Texas was very moist and quite unstable. Cells formed in or around the TRACON and moved ever so slightly to the north-northeast. There were numerous deviations around some cells at the NW gate, and the gate was closed for about 10 minutes around 18:02. There were also many deviations around a cluster of cells near the SE gate, and the gate was closed for about 20 minutes around 19:12. A single level 4 cell just north of the runways was penetrated by many aircraft just before landing. As this cell moved northward and away from the runways, the aircraft had enough room to deviate around it.

The airport was in a south configuration for the entire period and the traffic on this day was heavy. There were numerous penetrations and deviations of the cell near the runways, and of the storm cells near the SE gate.




**Air Traffic Management Logs**

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TIME  REMARKS
1100  SOUTH FLOW, DFW 108/ALR 116, 14 OVC.
1105  IAP ON.
1125  3 RTS WEST, ABI O/LBB, 10 MIT.
1205  DUAL RTE OVR BYP, 10 MIT.
1308  2 RTS WEST, TCC O/AMA, 10 MIT.  LBB O/ABI.
1333  DFW 114 RATE.  DUAL RTE BYP 1415 RUSH, 10 MIT, 4 A/C.
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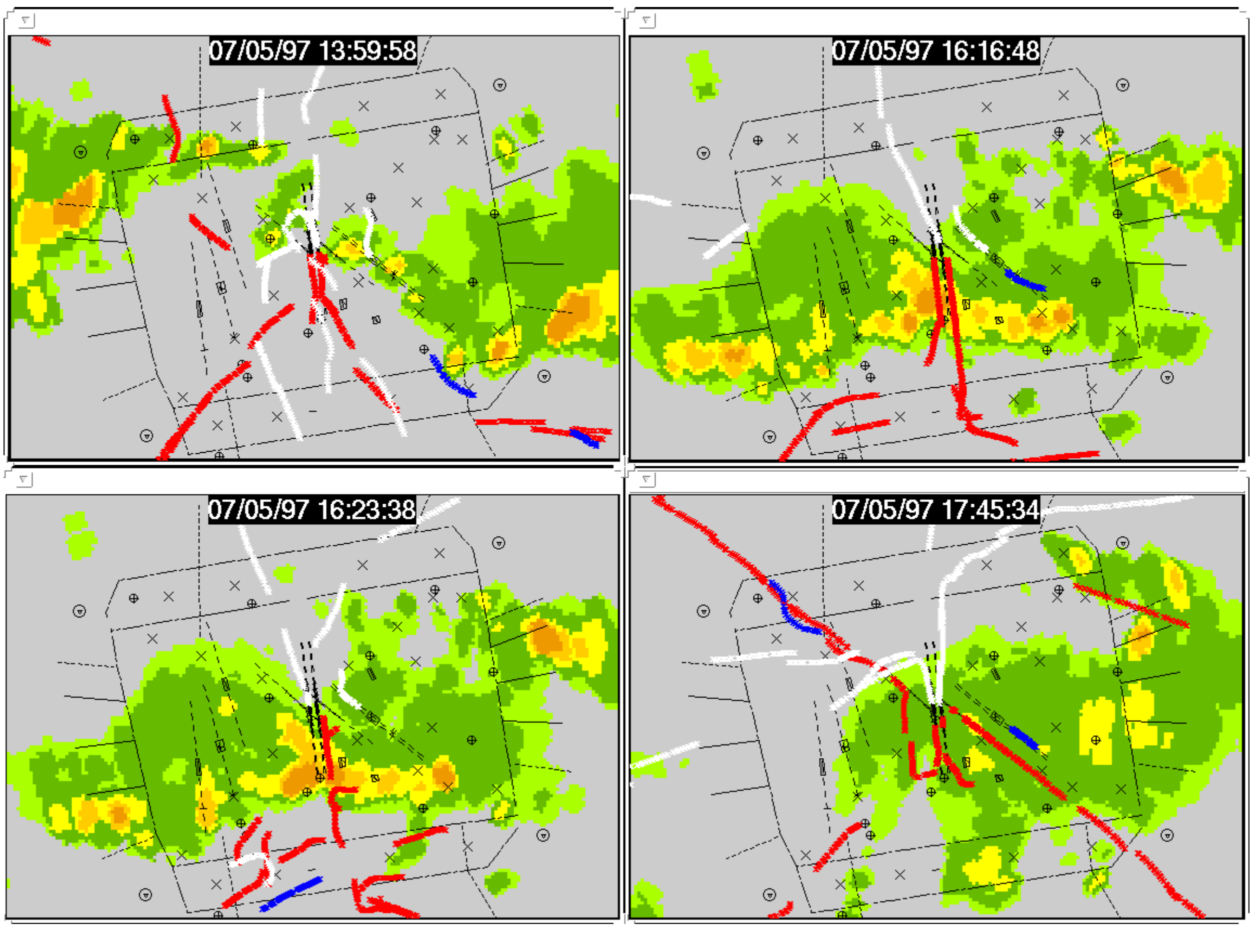
1456 IAP OFF.
1529 2 RTES WEST, TCC AND AMA OVR LBB, 10 MIT.
1540 DUAL RTE OVR BYP, 10 MIT.
1601 WEST GATE NORMAL SPACING.
1630 3 RTES SOUTH, AUS OVR ACT 10 MIT. 1 RTE WEST OVR ABI.
1652 2 RTES WEST, AMA AND TCC OVR LBB.
1731 3 RTES WEST, AMA OVR TCC.
1747 1 RTE WEST OVR ABI.
1751 2 RTES WEST, AMA AND TCC OVR LBB.
1757 5 MILES BETWEEN EAST DEPS FROM TWR ACCT WX EAST OF DFW.
1801 2 PROP RTES WEST, AMP AND TCP OVR LBP.
1802 STOP UKN DFW ARR ACCT WX DEVIATIONS.
1810 1 RTES NORTH, ADM OVR ZIM, 10 MIT.
1813 10 MIT OVR EIC.
1815 1 RTE WEST OVR ABI. DFW 96 RATE.
1818 CNL 5 MILE INTERNAL EAST REST.
1820 2 RTES SOUTH, TNV OVR CLL AND AUS OVR ACT, 10 MIT BOTH.
1825 DFW +15
1830 1 RTE SOUTH OVR CLL, 10 MIT.
1830 2 RTES WEST. SWAPS AND TCC/AMA ON 262R. LBB OVR ABI. 10 MIT BOTH
1835 2 RTES WEST, SWAPS AND AMA OVR TCC AND LBB OVR ABI, 10 MIT BOTH
1842 3 RTS EAST, 092 ON 082, 10 MIT 082R.
1843 2 RTES NORTH, ZIM OVR OKM.
1844 10 MIT OVR TXK.
1844 10 MIT ON CQY PROPS, CP 1900, MTD, 14 MIN DLA'S.
1901 DFW 84 RATE.
1902 DFW -15 MIN DLA'S.
1904 DFW ARR STOPPED DUE WIND SHEARS ON FINAL.
1922 RLS UKN ARRIVALS, 10 MIT.
1927 10 MIT OVR UKN, 10 MIT OVR BYP, 15 MIT OVR JEN, 20 MIT OVR CQY.
1932 1 RTE NORTH OVR OKM. 3 RTS WEST ADM O/AMA & LBB O/TCC. 2 RTS EAST TXK O/LIT & ELD & EIC ON 273R.
1935 15 MIT OVR UKN. CQY JET ARR 120.
1944 ONE RT EAST OVR LIT.
1946 10 MIT ON 1 RT EAST.
1956 DFW +15 DLAS.
2002 DFW 96 RATE, ALR 108.
2013 SWAP TXK AND LIT NORTH, 10 MIT, SWAP EIC AND ELD, SOUTH, 10 MIT.
2017 DFW +30 MIN DEP DLA'S, WX.
2018 4 RTS WST.
2022 ONE RT NORTH, RV 10 MIT.
2030 DFW -30.
2043 1 RT EAST OVR EIC.
2046 DFW -15 MIN DLA'S.
2056 2 RTES SOUTH, TNV OVR CLL AND AUS OVR ACT, 10 MIT BOTH.
2102 2 RTES EAST, LIT AND TXK ON 082R AND ELD AND EIC ON 092R, 10 MIT BOTH.
2104 DAL +15.
2117 DAL -15.
2119 4 RTES EAST, 10 MIT.
2133 DFW +15.

2153 CNCL SAT SWAP.
2200 ONE RT SOUTH ACT.
2205 DFW 114 RATE.
2212 DFW -15.
2215 CP 2224, MTD, 3 MIN DLA'S.
2245 2 RTS EASY, EIC AND ELD ON TXK, 10 MIT.
2258 SWAP MLC EAST EXCEPT ORD LANDERS.
2307 DUAL AT UKN At 0000 ARR RUSH.
2346 CP 2357, MTD, 7 MIN DLA'S.
2354 4 RTS EAST.
0025 TWR REQ 4 MIT 17L.
0027 3 RTS SOUTH, TNV ON CLL.
0040 4 RTS NORTH STD, XXCP SWAP ADM/JS2 TFC WEST OVR AMA.
0104 3 RTS EAST, LIT ON TXK.
0138 10 MIT ON 3 EAST RTS.
0151 CNCL ADM/J52 SWAP.
0155 DFW +15.  WX:  EAST RT RSTNS.
0205 DFW -15.
0230 COMB @ ASIC.

**July 5, 1997  1300 - 1830 UT – Weather and Air Traffic**

A stalled cold front was the catalyst for thunderstorm growth. The front had an east-west orientation and individual cells moved eastward while the front drifted slowly southward. From 15:00 to 16:30, there was a large region of level 3, 4 and 5 precipitation on the final approach path approximately 5 miles from the airport. The local controller asked each aircraft for a ride report and as long as the pilots reported a smooth ride or light chop, the arrivals continued to penetrate the storms. At 16:20 two planes chose not to penetrate the storms and the TRACON cut off the flow of arrivals for 30 minutes. The aircraft in the TRACON at 16:20 were re-routed to the east, around the storms, to land on the diagonal runway. On this day, each of the arrival routes was impacted by weather at some point during this period, closing each of the arrival gates for periods of time ranging from one half hour to several hours.

The airport was in a north configuration for the entire period and the traffic on this day was moderate to heavy. There were many penetrations of the storms near the airport and some deviations around storms near the arrival gates.




**Air Traffic Management Logs**

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TIME  REMARKS
1130  NORTH FLOW, 96 RATE PTOL 50, ALR 102.
1131  ONE RTE EAST OVR EIC.
1132  NEGATIVE CONTACT ITWS.
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1143 ONE RTE NORTH OVR ADM.
1150 10MIT EASTGATE.
1202 TWO RTES WEST AMA & TCC OVR LBB 10MIT.
1220 ONE RTE EAST OVR EIP.
1226 GRABE OVR BELCO UFN.
1232 ITWS CALLED AND WILL ACTIVATE SHORTLY.
1250 THREE RTES NORTH MLC/OKM.
1251 STOP EAST DEPARTURES STANDING BY FOR SWAP.
1256 ONE RTE NORTH OVR ADM.
1301 SWAP LIT/TEK/ELD NORTH OVR ADM.
1303 DFW +15.
1306 STOP DAL.
1325 DFW +30.
1332 ONE WEST OVR MQP 10MIT.
1359 DFW +45.
1405 RESUME DAL ARRIVALS.
1406 STOP UKW ARRIVALS WX.
1411 IAP ON.
1425 FOUR RTES NORTH RADAR.
1426 STOP WEST DEPARTURES.
1430 SWAP AMA/TCC NORTH OVR ADM 10MIT. SWAP LBB/ABI SOUTH OVR ACT 10MIT.
1431 DFW -45.
1437 STOP DFW ARRIVALS TRW ON AFT.
1449 RESUME DFW ARRIVALS @ 60 RATE.
1455 DFW -30.
1500 ONE RTE EAST 10MIT PROP RADAR VECTORS.
1501 ONE RTE NORTH 10MIT RADAR VECTORS.
1505 DFW +30.
1508 STOP JET DEPARTURES.
1509 SKYDIVE TEXAS ACTIVE.
1515 ONE RTE EAST PROPS 10MIT.
1519 ONE RTE EAST OVR LIT 10MIT CKL SWAPS, EXCEPT EIC.
1521 RESUME DEPARTURES.
1525 DFW +45.
1543 STOP SOUTHBOUND JET DEPARTURES.
1545 REQUESTED HELP FROM COMMAND CENTER DUE TO TWO DEPARTURES RTES ONLY 10MIT.
1553 TWO RTES NORTH ZIM/ADM & MLC/OKM 10MIT.
1608 SWAP WEST GATE NORTH OVR ADM 15MIT SWAPS ONLY.
1601 EAST DEPARTURES STOP WX.
1606 ONE RTE EAST OVE BYP 10MIT.
1608 SWAP SOUTHGATE OVE BYP 10MIT.
1619 STOP DFW ARRIVALS TRW+ ON FINAL.
1635 DAL +15 @1620 & +30 @1635.
1640 DFW +90.
1645 NORTH SWAPS 10MIT.
1646 TEST JET OVR UKW.
1659 ONE RTE WEST OVR AMA/10MIT.
1708 RESUME DFW ARRIVALS FROM UKW & JEN @ 60 RATE.
1715 DFW +30.
1717 FTW +15.

1725 TWO RTE WEST AMA/TCC & LBB/ABI 10MIT.
1727 CQY ARRIVALS 10MIT.
1732 SWAP ACT & AUS WEST OVR ABI 10MIT.
1754 DFW -30.
1806 DFW -15.
1809 IAP OFF.
1810 ONE RTE SOUTH OVR ACT 10MIT.
1813 DFW 102 RATE.
1820 FOUR RTES NORTH RADAR.
1833 CP 1850 MTD 5 MIN DLAS.
1844 ONE RTE EAST ANYWHERE 10 MIT.
1855 DFW 96 RATE.  IAP ON.
1909 THREE RTES WEST LBB ON TCC ALL RTES STANDARD.
1911 DFW 114 RATE.
1924 TWO RTES EAST, ELD ON EIC 10 MIT, TKK ON LIT 10 MIT.
1953 IAP OFF, DF W120 RATE.
2013 TWO RTES SOUTH, AUS ON ACT, INV ON CLL.
2025 FOUR RTES WEST.
2033 DFW + 15, FOUR RTES SOUTH STANDARD.
2037 THREE RTES EAST, TKK ON LIT 10 MIT.
2040 FOUR RTES EAST STANDARD.
2102 DFW -15.
2200 GRABES OUT ELECO UFA.
2332 TWO RTES WEST AMA, TCC ON LBB 10 MIT.
0010 TWO AC ON DUAL RTE OVR BYP.
0100 DFW SOUTH FLOW, UKN ARR OVR MASTY STANDARD.
0216 TWO RTES WEST, TCC ON AMA, LBB ON ABI.
0250 ONE RTE WEST OVR ABI 10 MIT.  DUAL RTE OVR BYP.
0300 COMBINED AT ASIC

## GLOSSARY

| | |
|---|---|
| AP | Anomalous Propagation |
| ARTCC | Air Route Traffic Control Center |
| ASQP | Airline Service Quality Performance |
| ASR | Airport Surveillance Radar |
| CTAS | Center-TRACON Automation System |
| DFW | Dallas-Ft. Worth |
| DZ | Radar reflectivity |
| FAA | Federal Aviation Administration |
| ITWS | Integrated Terminal Weather System |
| LLWAS | Low-Level Wind Shear Alert System |
| MAXVAL | Maximum reflectivity in a column |
| MIT | Miles-in-trail |
| MIT/LL | Massachusetts Institute of Technology Lincoln Laboratory |
| NASA | National Aeronautics and Space Administration |
| NEXRAD | Next Generation Weather Radar |
| NLDN | National Lightning Detection Network |
| NWS | National Weather Service |
| PDT | Product Development Team |
| PODEV | Probability of Deviation |
| PVD | Plan View Display |
| TAP | Terminal Area Productivity |
| TDWR | Terminal Doppler Weather Radar |
| TRACON | DFW Terminal Radar Approach Control |
| URET | User Request Evaluation Tool |
| VIL | Vertically Integrated Liquid Water |
| VIP | Video Integrated Processor (NWS six-level weather scale) |

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