AN ANALYSIS OF MICROBURST CHARACTERISTICS RELATED TO AUTOMATIC DETECTION FROM HUNTSVILLE, ALABAMA AND DENVER, COLORADO

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1. INTRODUCTION

During 1986 and 1987–1988, Lincoln Laboratory, under the sponsorship of the Federal Aviation Administration (FAA), collected Doppler radar measurements in Huntsville, Alabama and Denver, Colorado, respectively. These field programs focused on developing and evaluating an automated wind shear detection system that would provide timely warnings of hazardous low-altitude wind shear events to pilots in the airport terminal area.

Two previous projects in Denver (JAWS and CLAWS) documented the ability of a pulsed Doppler radar system to detect wind shear near an airport. In the last two decades, there have been 27 aircraft accidents or incidents at least partially attributed to this phenomenon. According to the National Transportation Safety Board, the most hazardous form of wind shear to aviation is the microburst, first identified by Fujita (1981). A microburst is an outflow of downdraft winds from a convective cloud which exhibits a strong divergent pattern near the surface. The radial velocity differential (ΔV) must be ≥ 10 m/s over a distance of 4 km or less to be classified as a microburst.

In this paper, microburst measurements from the TDWR testbed are analyzed to characterize and compare the type of outflows in an environment with a typically dry sub-cloud layer (Denver) and a typically moist sub-cloud layer (Huntsville), and to relate these characteristics to observable radar features being used in the Terminal Doppler Weather Radar (TDWR) system for microburst detection. Section 2 describes the primary radar used in the data collection program. Section 3 contrasts microburst characteristics from the two locales. Evidence is presented which suggests that the reflectivity and intensity of the outflow are important to the performance of the microburst detection algorithm, while the frequency and intensity of features aloft may provide for an earlier declaration of a microburst. In Section 4, key microburst characteristics from Huntsville and Denver are summarized in relation to the automatic detection process.

2. THE DATA

The data reported here were collected by the FAA-Lincoln Laboratory TDWR testbed radar which operated at S-band, using a 1° pencil beam antenna (Evans and Johnson, 1984). The testbed measurements included an antenna scan strategy that provided a higher surface update rate (1.5 minutes in Huntsville and 1 minute in Denver) than the previous CLAWS and JAWS projects. In Denver, the radar scanned to a maximum elevation of 40° every 2.5 minutes in order to detect precursors to the microburst flow. In addition, the TDWR testbed includes advanced data quality techniques such as clutter filtering (Evans, 1983), clutter residue mapping (Mann, 1988), and the automatic selection of the PRF to minimize range obscuration by out-of-trip weather echoes (Crocker, 1988). Thus, because of the rapid update rate, the overall storm coverage, and the minimization of data contamination, the TDWR measurements in Denver provided much better quality data than that collected during many previous microburst studies.

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3. RESULTS

As shown in Table 1, there were twice as many (480 versus 240) real-time windshear detections in Denver (1987) than in Huntsville (1986). Microburst activity peaked during June–August in Denver and July–September in Huntsville. The maximum number of daily microbursts occurred in the afternoon hours (4–6 p.m. LDT in Denver and 2–4 p.m. LDT in Huntsville). There were over 60 microburst days at each locale. At least 5 events were detected on 53% of the Denver microburst days and 40% of the Huntsville microburst days. That certain days are more favorable for microburst development than others is emphasized by the fact that 8% of the Huntsville events and 5% of the Denver events were detected on one day. Wolfson (1988) reported that the development of potential microburst producing cells along the outflow of previous events was common in Huntsville, creating "families" of microbursts. Thus, the detection of the initial wind shear in a region is a clue to the possible formation of additional microbursts.

Table 1. Microburst project statistics from the 1986 (Huntsville) and 1987 (Denver) TDWR testbed operations.

	HUNTSVILLE (1986)	DENVER (1987)
Data Collection Period	Mar 1–Dec 31	May 7–Dec 31
No. of Days of Data Collection	81	106
No. of Microbursts	240	480
No. of Microburst Days	64	68
No. of Days $\geq$ 5 Events	25	36
Peak Months	Jul–Sept	Jun–Aug
Peak Daily Microbursts	19	25
Peak Time Period (LDT)	1400–1600	1600–1800

A. Microburst Peak Reflectivities

The peak surface reflectivity of a microburst producing storm is a possible indicator of outflow intensity. The maximum surface reflectivity within Denver microbursts ranged from 0 to 60+ dBz (Figure 1). It should be noted that one-half of the microburst cells in Denver were wet with a maximum surface reflectivity of >35 dBz. In contrast, the majority (94%) of microburst cells in Huntsville had surface reflectivities of 50 dBz or greater, with a minimum of 40 dBz.

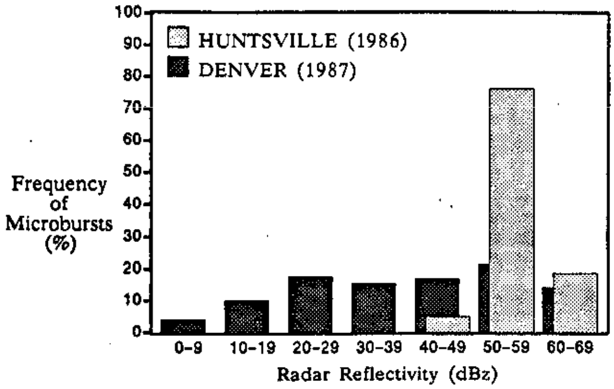

Fig. 1. Distribution of the maximum surface radar reflectivity factor in cells that produced microbursts.

Studies of Memphis microbursts by Rinehart and Isaminger (1986) showed no obvious relationship between the maximum surface reflectivity in 5 dBz intervals and the intensity of the microburst nor was any such relationship observed in JAWS. Figure 2 is a least squares nonlinear fit of the maximum liquid water content (in 1 dbz intervals) versus the maximum ΔV for a subset of Huntsville microbursts. The equation used to convert the maximum reflectivity to liquid water content was derived from airplane measurements through a Memphis thunderstorm (Burrows and Osborne, 1986). There was a significant relationship between liquid water content and outflow intensity for Huntsville microbursts. The best fit curve in Figure 2 suggests that as the liquid water content increases, so does the surface outflow ΔV. There was a 4.3 m/s standard error of estimate for predicting the ΔV based on the maximum liquid water content.

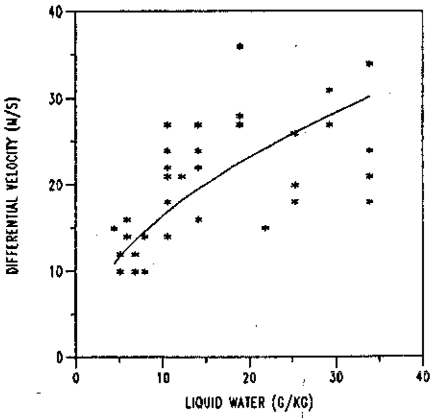

Fig. 2. Maximum radial velocity differential plotted against liquid water content for Huntsville.

Low reflectivities within the outflow could affect the detection performance of the microburst algorithm. If the signal-to-noise ratio is lower than the threshold used by the algorithm, an outflow could go undetected or underestimated by the system. The minimum reflectivity within the outflow region of thirty-three dry microbursts from Denver ranged from +15 to -9 dBz, with a median of -3. In fact, two-thirds of the events had a minimum outflow reflectivity of less than 0 dBz. One of the lowest reflectivity microbursts on July 9 produced a peak ΔV of 30 m/s. Low reflectivities within the outflow were partially responsible for several missed detections by the algorithm during the 1988 Denver tests.

B. Microburst Velocities

The magnitude of the surface outflow ΔV in a microburst is closely coupled to the detection capability of the algorithm. In this paper we define four microburst categories based on the intensity of the outflow as follows: weak (10-14 m/s), moderate (15-19 m/s), strong (20-24 m/s), and severe (≥25 m/s). This is consistent with the velocity categories developed by Lincoln Laboratory for the purpose of scoring the microburst algorithm. Campbell et al. (1989) reported a low algorithm detection rate (85%) for events less than 20 m/s. A further evaluation of Huntsville and Denver algorithm misses revealed that 48% had a maximum ΔV of 12 m/s or less. Figure 3 is a frequency plot of the number of microbursts observed in real time versus intensity. There was a

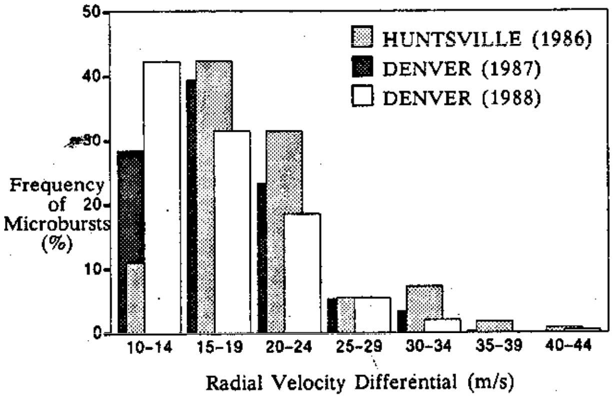

Fig. 3. Distribution of the maximum radial velocity differential across microbursts observed in real time.

higher frequency of strong and severe events in Huntsville, while the Denver (1987) data set contained a larger percentage of weak events (28% vs. 11%).

The intensity of Denver microbursts during 1988 was plotted to determine if the velocity distribution was consistent with 1987 results (Figure 3). A high percentage (40%) of these events were categorized as weak. Among the possible explanations are: 1) the display of the microburst algorithm detections in real time during 1987 and 1988 allowed radar operators to improve their observations of weaker shears, and 2) Denver has a larger percentage of weak microbursts.

C. Microburst Outflow Depths

The outflow depth (altitude) in a microburst is significant since a shallow outflow may go undetected by the radar system. For this analysis, the depth of outflow is defined as the height at which one-half the maximum surface velocity is observed. Based on this definition, Huntsville wind shears were shallower than those at Denver (0.4 km versus 0.6 km. respectively). At a height of 200 to 300 meters, the ΔV in the shallowest outflows was reduced by 50%. The median height of maximum velocity for both locales was within the lowest 60 meters AGL. Figure 4 is a plot of outflow depth and maximum surface reflectivity for Huntsville and Denver microbursts. There is some correlation (-0.48) between the out-

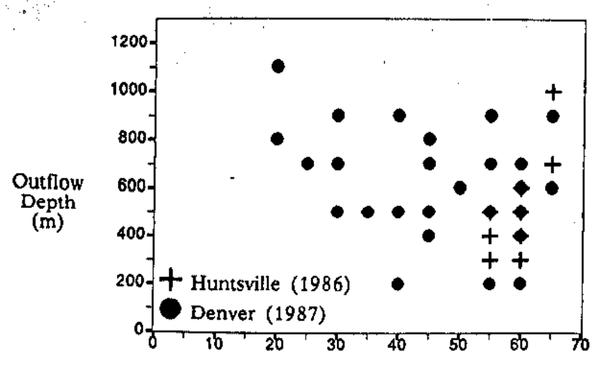

Fig. 4. Outflow depth vs. maximum surface reflectivity

flow depth and core reflectivities in Denver. The data analyzed here suggest that the low reflectivity storms produce the deepest outflows, with more variability in the moderate and high reflectivity wind shears.

D. Microburst Cloud Top Height

It appears that the strongest outflows are associated with storms that attain the highest cloud tops. There is a positive relationship between 20 dBz cloud top height and maximum ΔV for both data sets (Figure 5). The correlation for Huntsville is stronger, with a coefficient of 0.73, while the coefficient for Denver is 0.23. For example, a Huntsville outflow of 15 m/s had a parent storm cloud height of 6.5 km, while all Huntsville surface outflow ΔV's in excess of 20 m/s were associated with 20 dBz storm top heights greater than 10 km. Also, the non-microburst producing cells in Huntsville did not attain the cloud top heights of those that produced microbursts.

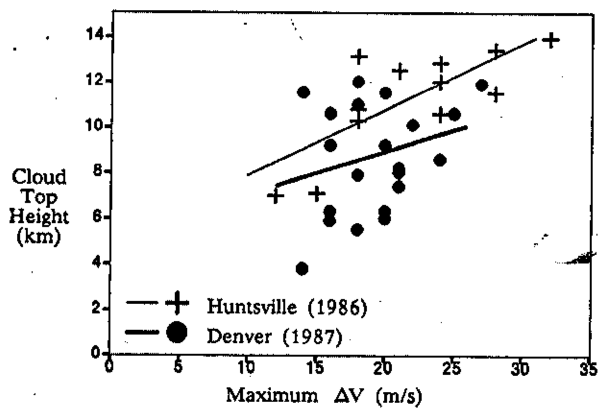

Fig. 5. Cloud top height vs. maximum ΔV.

E. Microburst Precursors

The frequency and strength of precursors (features aloft) detected within Huntsville and Denver microburst storms will be examined next. Campbell and Isaminger (1989) reported that the detection of features aloft by the algorithm can provide an earlier wind shear declaration. Based on JAWS data, Roberts and Wilson (1984) suggested that convergence aloft and a descending core were good indicators of a downdraft in Denver, with mid-level rotation of secondary importance. Eilts (1987) reported the significance of a descending core and mid-level convergence in Oklahoma downbursts, while Isaminger (1987) observed that a descending core and divergent tops were often precursors to microbursts in Huntsville. Other radar features that have been suggested as potentially useful in predicting a microburst are lower-level divergence, reflectivity notches, sinking tops, and hail flare descent.

In our study we have focused on five common precursors: mid-level rotation, mid-level convergence, upper-level divergence, lower-level divergence, and descending reflectivity cores. Velocity features were declared based on a ΔV of at least 10 m/s. The altitude extent was defined as follows: lower-level divergence (< 1 km AGL), mid-level rotation and convergence (1–7 km AGL), and upper-level divergence (> 7 km AGL). Reflectivity cores were characterized by: 1) a maximum reflectivity of 50 dBz or greater, 2) the maximum reflectivity must develop at a height > 2.5 km AGL, and 3) the depth of the reflectivity core must exceed 5.2 km (Isaminger, 1987). The core is considered descending once it falls below 2 km AGL.

Mid-level rotation and convergence were observed in approximately the same percentage (50%) of Denver and Huntsville microbursts (Figure 6). A descending core was detected in over 90% of the Huntsville wind shears, while less than 10% of the Denver events exhibited a descending core based on our thresholds. This may suggest a need to use lower thresholds in Denver for declaring descending reflectivity cores. In addition, more than 90% of the Huntsville events displayed upper-level divergence during the microburst's life cycle, whereas this feature was detected in less than 10% of the Denver storms. Approximately two-thirds of the microbursts in Denver and Huntsville exhibited lower-level divergence.

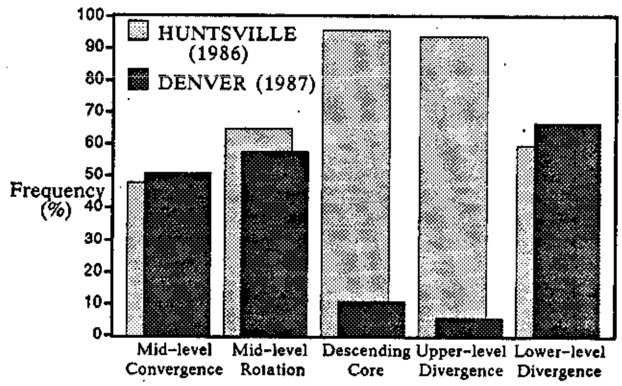

Fig. 6. Comparison of upper-altitude feature frequency for Huntsville and Denver microburst producing storms.

Lower-level divergence was further investigated to determine the time of its initial occurrence in Huntsville and Denver microbursts. Fujita (1985) first documented this phenomena during the JAWS project and coined the term "mid-air microburst". Theoretical expectations are that the less dense downdrafts typical of dry microbursts in Denver would have greater mid-air divergence. Lower-level divergence was detected prior to the microburst outflow in 75% of the low and moderate reflectivity Denver cases (Table 2). By comparison, relatively few (2%) Huntsville microbursts had lower-level divergence prior to a surface outflow of 10 m/s. For the Denver events, there was a median time difference of 0.8 minutes between the initial detection of lower-level divergence and a 10 m/s outflow. Lower-level diver-

Table 2. Lower-level divergence statistics for Huntsville (1986) and Denver (1988).

	Huntsville	Denver
Frequency of Microbursts Exhibiting Lower-Level Divergence Prior to 10 m/s Outflow	2%	75%
Median Time Difference Between Lower-Level Divergence and 10 m/s Outflow	-1.9	0.8

gence did not appear to be a useful predictor of Huntsville microbursts since it was typically detected two minutes after the microburst. During the 1988 Denver tests, lower divergence was the predominant feature (31%) used to declare the initial microburst event.

Roberts and Wilson (1986) in an investigation of JAWS and CLAWS outflows categorized events based on the maximum reflectivity: low ($\leq$ 35 dBz), moderate (40-50 dBz), and high ($\geq$ 55 dBz). Figure 7 is a frequency distribution of features aloft for the 1987 Denver data set based on the reflectivity classification scheme of Roberts and Wilson. More than 60% of the moderate and high reflectivity storms contained evidence of mid-level rotation or convergence. Descending cores were detected in all of the high reflectivity microbursts. Of the moderate and high reflectivity storms, less than 20% displayed upper-level divergence. It is obvious from the results depicted in figure 7 that there are fewer features aloft in the low reflectivity microbursts.

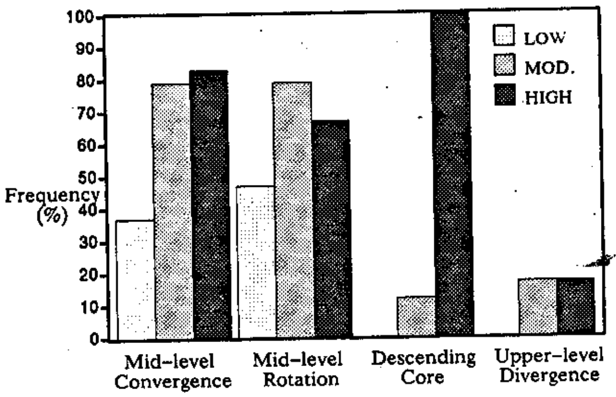

Fig.7. Frequency of Denver microbursts exhibiting upper-altitude features for low, moderate, and high reflectivity categories.

The frequency of features aloft for Huntsville (1986) and Denver (1987) based on surface outflow ΔV is presented in Table 3. Mid-level rotation or convergence was detected in less than 45% of the weak microbursts in Huntsville and Denver. In both locations, there was a greater likelihood for features aloft in the strong events. Figure 8 is a plot of the frequency of mid-level convergence based on the surface outflow ΔV for Denver and Huntsville. The intensity of mid-level convergence was typically stronger for Huntsville events. In general, low reflectivity microburst storms in Denver were associated with weaker convergence aloft. Hjelmfelt (1987) reported that the observability of convergence above microburst lines in the High Plains (Denver area) is dependent on the viewing angle. If the radar scans the minimum radial velocity axis of the cell there is a chance the mid-level convergence will go undetected.

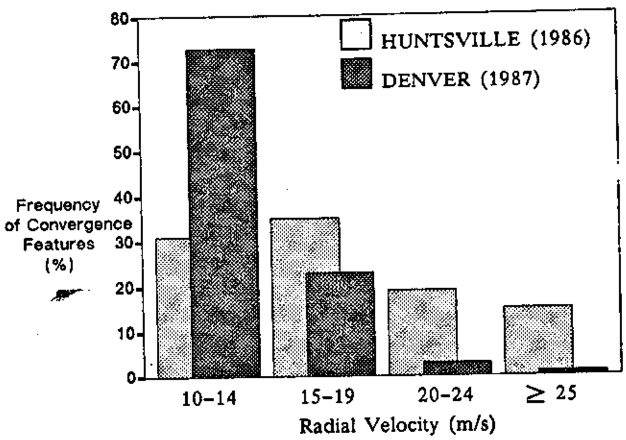

Fig. 8. Frequency of mid-level convergence as a function of radial velocity.

Another issue evaluated is the relationship between the strength of the outflow and the feature aloft to determine if a quantitative prediction of the maximum outflow intensity can be made. Eilts (1987) reported a positive correlation between surface divergence and convergence aloft for a limited number of Oklahoma storms. Our research from Huntsville and Denver suggests the strength of the outflow is moderately related to the intensity of the feature aloft. In general, stronger outflows are accompanied by stronger features, and weaker outflows by weaker features. However, there is some variability as reflected by the correlation coefficients for Denver which were +0.95 (upper-level divergence), +0.40 (rotation), and +0.49 (convergence). The correlation coefficients for Huntsville were +0.68 (upper-level divergence), +0.61 (rotation),

Table 3. Frequency of features aloft based on microburst differential velocity.

	Mid-level Rotation			Mid-level Convergence			Descending Core		
Velocity (m/s)	10-14	15-19	$\geq$ 20	10-14	15-19	$\geq$ 20	10-14	15-19	$\geq$ 20
Huntsville	44	64	75	33	54	50	86	100	100
Denver	33	64	67	28	48	73	0	9	20

and +0.63 (convergence). For each locale, the strength of the outflow is most closely related to the intensity of upper-level divergence (Figure 9).

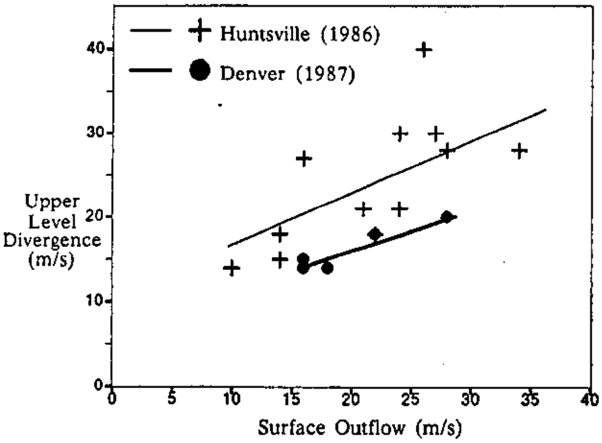

Fig. 9. Upper-level divergence vs. surface outflow.

4. SUMMARY

This paper compared microburst characteristics from an environment with a typically dry sub-cloud layer (Denver) and a typically moist sub-cloud layer (Huntsville). There was a significant relationship between the maximum liquid water content of the storm core and the maximum outflow intensity for Huntsville microbursts. Results from JAWS suggested no such relationship in Denver microbursts. The minimum surface reflectivity within the outflow regions of dry microbursts in Denver was typically less than 0 dBz. This could significantly effect the ability of the radar system to detect low reflectivity wind shear events in a severe clutter environment.

In real time, there was a higher frequency of weak microbursts detected in Denver than in Huntsville. This is possibly related to the real time display of the microburst algorithm detections in 1987-88 which allowed radar operators to better observe the weaker shear events. The distribution of severe events between the two locales is similar.

There is evidence the cloud top height of Huntsville storms is correlated with the maximum outflow velocity. Huntsville storms that obtained higher cloud top heights were more likely to produce a stronger wind shear.

In order to provide timely detection of microbursts in diverse climatic regions, detailed information is needed on the types of features that may precede or accompany the surface outflow. In Huntsville, the most dominant precursors were a descending high reflectivity core and divergent storm tops. Nine of the ten Huntsville storms that were scanned adequately had a descending core and divergent tops. In comparison, lower-level divergence was detected prior to the microburst outflow in 75% of the Denver events but only 2% of the Huntsville cases. This analysis suggests that the use of lower-level divergence as a precursor may be limited to dry microburst regions. The intensity of mid-level convergence was typically stronger for the Huntsville events. In general, low-reflectivity microburst storms in Denver were associated with weaker convergence aloft. For both locales, the intensity of the surface outflow is proportional to the magnitude of divergent storm tops.

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