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A Preliminary Study of Precursors to Huntsville Microbursts

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16. Abstract

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ABSTRACT

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CONTENTS

LIST OF ILLUSTRATIONS

ACRONYMS

ATC	Air Traffic Control
FAA	Federal Aviation Administration
FLOWS	FAA-Lincoln Laboratory Operational Weather Studies
FL-2	FAA-Lincoln Laboratory S-band Doppler Radar
NEXRAD	Next Generation Weather Radar
PPI	Plan Position Indicator
RHI	Range Height Indicator
TDWR	Terminal Doppler Weather Radar

MICROBURST PRECURSORS

1.0 INTRODUCTION

Previous studies have shown microbursts to be hazardous to airplanes, especially during takeoffs and landings (Wilson and Roberts, 1983 and Wilson et al., 1984). Research indicates most windshears peak within 10 min of the initial outflow (Wilson et al., 1984). Precursor recognition could provide valuable warning time of an impending event. Additionally, precursor features may provide information on the severity of a microburst beyond that available from measurements of the surface divergence. Among the proposed features are rotation, convergence, descending reflectivity core, and reflectivity notching*. In this report, upper-level divergence has also been considered as a possible microburst precursor.

A precursor is defined as a radar detectable feature within a microburst producing storm which precedes or accompanies the surface divergence. The timely detection of precursors could:

1) improve the reliability in estimating the magnitude of the associated surface winds,

2) allow early declaration of weak events which will subsequently achieve operationally significant levels,

3) provide warning of a surface divergence before it occurs.

A model for microburst precursor detection has been developed at Lincoln Laboratory by Campbell (1987). This system distinguishes precursors into mid and upper-level features based on the altitude regime in which the phenomena is measured and its location in relation to regions of high reflectivity. Reflectivity levels above 50 dBz are currently being used to define "storm cores" for microburst producing storms in the southeast. An upper-altitude precursor is characterized by a reflectivity core accompanied with convergence above 2 km AGL (Campbell, 1987). A mid-level precursor is defined by a core in association with either convergence or rotation at an altitude of 1.0 to 2.5 km (Campbell, 1987).

*A reflectivity notch is distinguished by an area of weaker reflectivity surrounded by stronger reflectivity within a storm cell.

2.0 DATA ANALYSIS

In order to evaluate possible precursors, 34 microburst and 23 null cases were examined from the 1985 and 1986 FLOWS data-set. Each radar tilt was analyzed for the presence of precursors and the maximum reflectivity to be included as "truth" for automated precursor detection algorithms. The importance of individual features will be discussed along with regional differences.

2.1 Scan Strategy

The data analyzed in this study were gathered during 1985 and 1986 by the FL-2 pulsed Doppler radar which operated in a mixed PPI and RHI mode (Evans and Johnson, 1984). A typical scan sequence of 4 min duration used 4 surface outflow detection tilts and 12 upper-level precursor tilts. The update rate at the surface was approximately 1 min. Each volume scan provided measurements 0.6 km apart vertically to a height of 7 km at the nominal detection region (15 km). Storms farther than 15 km had a proportionally coarser resolution. The depth of rotation was obtained on successive PPI tilts with spatial continuity assumed within the gaps. The vertical extent of convergence was determined from RHI scans.

2.2 Criteria For Precursor Detection

The criteria used to identify individual precursors is an important element of microburst detection algorithm development. The minimum threshold for velocity features such as rotation, convergence, and divergence was a radial differential of 10 m/s. This is the typical shear value used in previous studies in defining microbursts based on the surface velocity field. The validity of using this particular value to declare features aloft needs further investigation. The current microburst detection algorithm utilizes a 10 m/s threshold for all velocity features.

A reflectivity core was defined by a depth of 5.2 km for the area within the 50 dBz contour. It was considered descending if it formed above 3 km and tracked to the surface. Notches were declared whenever the reflectivity contours decreased toward the center of the cell.

The 'flare' distinguished in this report has been discussed by Wilson and Reum (1986), Fujita (per. comm.), and Zrnic' (1987). Generally, it is characterized by an elongated spike in reflectivity and velocity on the backside of the core. Figure 1 illustrates a reflectivity spike recorded by the FL-2 radar on 24 August 1986 in Huntsville.

There was no threshold on the maximum height of an individual feature. Within a storm, divergent tops would be considered an upper-level event (> 6 km), while convergence and rotation usually occurred at mid-levels (1-6 km).

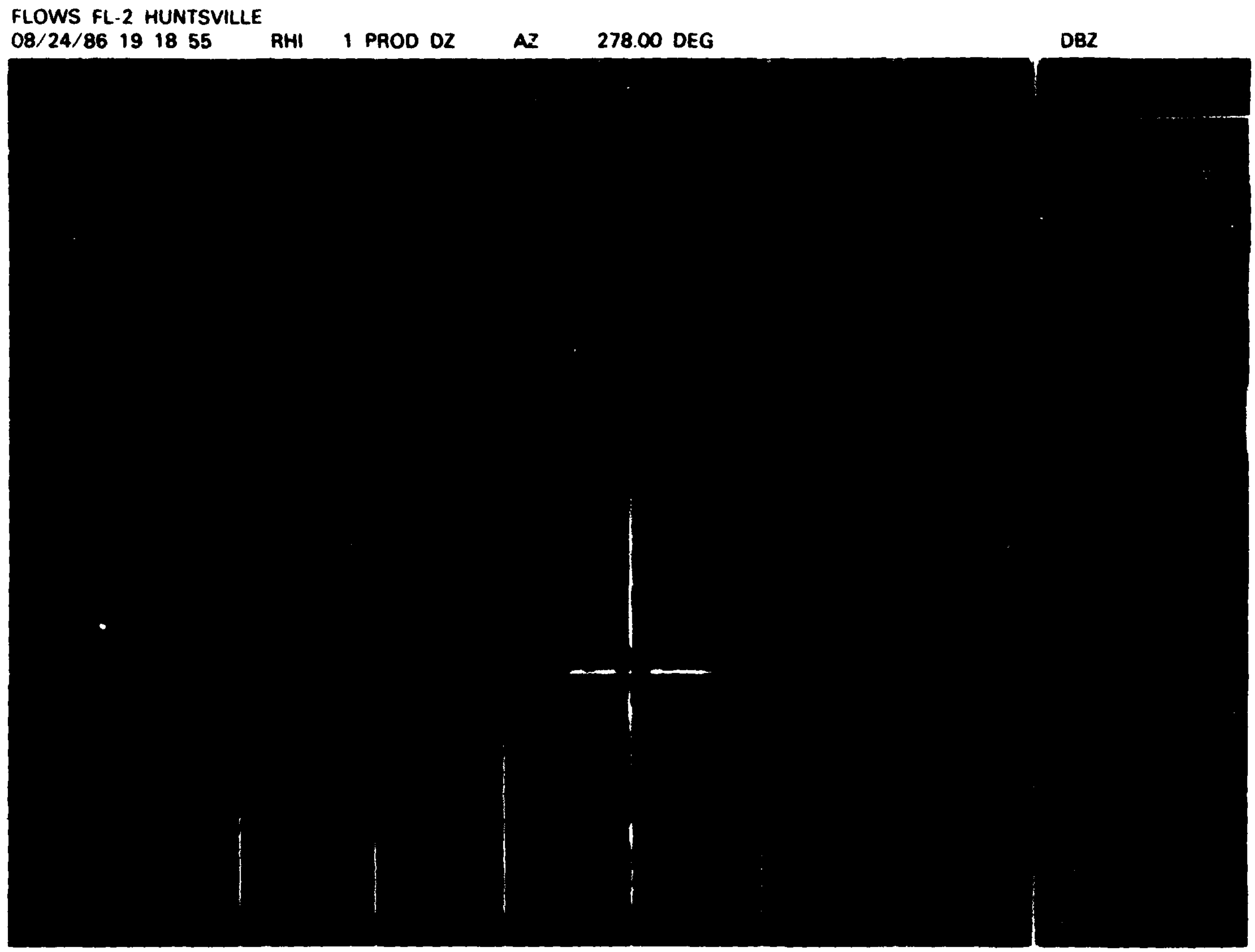

Fig. 1. Hail spike as portrayed in reflectivity field.

3.0 PRECURSOR STATISTICS

As shown in Table 1, 95% of the microburst producing storms exhibited a descending core while 41% contained evidence of convergence. Rotation was detected in over 1/2 of the events. Nine of ten microburst cells portrayed divergent tops. In the southeastern U.S., a descending core and divergent tops appear to be the most common precursors. Features such as rotation and convergence play a lesser role. This is contrasted to results in the High Plains (Roberts and Wilson, 1986) and Oklahoma (Eilts, 1987) where convergence is a persistent feature. Due to regional variability, a microburst algorithm should consider the precursors identified above as well as the flexibility for site adaptation.

Table 1. Huntsville, Alabama, microburst producing storms individual precursor detections

Date/Event #	Mid-Level Rotation	Mid-Level Convergence	Descending Core	Divergent Tops
24 AUG 85/1	Y	N	-	-
06 JUL 86/1	Y	N	-	Y
06 JUL 86/2	Y	N	-	Y
06 JUL 86/3	N	N	-	-
11 JUL 86/2	N	N	-	Y
11 JUL 86/3	N	N	Y	-
11 JUL 86/4	Y	N	-	Y
11 JUL 86/5	N	N	-	-
25 JUL 86/1	Y	Y	Y	-
25 JUL 86/2	Y	N	-	Y
25 JUL 86/3	N	Y	Y	-
25 JUL 86/4	Y	N	Y	-
25 JUL 86/5	N	N	Y	-
25 JUL 86/6	Y	Y	-	Y
25 JUL 86/7	Y	N	Y	-
31 JUL 86/1	N	Y	Y	Y
31 JUL 86/2	N	Y	Y	-
31 JUL 86/3	N	N	Y	N
31 JUL 86/4	N	N	Y	-
31 JUL 86/5	Y	N	-	-
31 JUL 86/6	Y	Y	-	-
31 JUL 86/7	Y	Y	Y	Y
07 AUG 86/1	Y	Y	Y	-
07 AUG 86/2	Y	N	Y	-
24 AUG 86/1	Y	Y	Y	Y
24 AUG 86/2	Y	N	Y	-
24 AUG 86/3	N	N	Y	Y
24 AUG 86/4	N	N	N	-
24 AUG 86/5	N	Y	Y	Y
20 SEP 86/1	Y	Y	Y	Y
21 SEP 86/1	Y	N	Y	Y
21 SEP 86/2	N	Y	Y	-
21 SEP 86/3	Y	Y	Y	-
21 SEP 86/4	Y	Y	-	Y
	20/34(59%)	14/34(41%)	21/22(95%)	14/15(93%)

Y = YES
N = NO
- = scan strategy did not yield data to determine whether a feature was present or not

4.0 HEIGHT AND DEPTH

The height and depth of precursors are a key factor in designing microburst detection scan sequences. Table 2 lists the height and depth of rotation for 13 microburst storms. The data was gathered from PPI elevation tilts. The height of rotation varied from 0.3 to 5.4 km. Several cases exhibited circulation at two different levels within a storm. The median depth was 1.4 km. Almost all of the events could have been detected by a TDWR volume scan with 1 km vertical resolution. This type of scan will be tested and evaluated in Denver during 1987.

Table 3 provides the height and depth of convergence for 27 microbursts. The depth ranged from 0.7 to 3.4 km, while the height varied from 1.3 to 6.9 km. Thus a TDWR should scan to 6.9 km AGL to consistently detect mid-level precursors in the southeast.

Table 2. Height and depth of rotation for FLOWS microbursts.

Case #	Date	Time gmt	Height km	Depth km
1	8-24-86	190815	0.3-0.7	0.4
2	8-07-86	211047	4.3-5.4	1.1
3	8-07-86	214108	2.3-3.9	1.6
4	8-24-85	144200	2.3-4.3	2.0
5	8-24-85	163400	1.3-2.4	1.1
6	8-24-85	172118	1.6-3.1	1.5
7	8-24-85	175257	0.9-2.5	1.4
8	8-10-85	192350	2.6-3.8	1.2
18	7-06-86	205310	2.7-3.8	1.1
24	9-21-86	185203	1.6-3.5	1.9
25	9-21-86	193225	2.5-4.5	2.0
26	7-01-86	212738	1.4-2.8	1.4
27	9-20-86	210200	1.5-3.0	1.5
			MEDIAN-	1.4

Table 3. Height and depth of convergence for FLOWS microbursts.

Case #	Date	Time gmt	Height km	Depth km
1	8-24-86	191443	5.1-6.6	1.5
2	8-07-86	211315	2.4-4.3	1.9
3	8-07-86	214122	2.5-3.3	0.8
4	8-24-85	142141	3.6-5.4	1.8
5	8-24-85	165118	2.6-5.2	2.6
6	8-24-85	180400	2.1-3.0	0.9
7	8-24-85	165404	4.2-5.3	1.1
8	8-10-85	185902	2.3-3.4	1.1
9	7-25-86	192902	4.6-6.0	1.4
10	7-25-86	202523	2.9-3.6	0.7
11	7-25-86	220615	1.7-4.8	3.1
12	7-31-86	175157	1.8-4.7	2.9
13	7-31-86	175413	2.3-5.1	2.8
14	7-31-86	182216	1.7-3.7	2.0
15	7-31-86	191905	2.6-3.8	1.2
16	7-06-86	204641	2.6-3.5	0.9
17	7-13-86	203705	3.5-5.2	1.7
18	7-06-86	210906	3.2-4.8	1.6
19	9-20-86	210526	1.3-4.4	3.1
20	9-26-86	174141	2.7-4.0	1.3
21	9-26-86	183028	3.4-5.2	1.8
22	9-26-86	183533	3.5-6.9	3.4
23	9-26-86	190211	2.8-4.5	1.7
24	9-21-86	192032	2.4-5.2	2.8
25	9-21-86	192527	2.1-3.6	1.5
26	7-01-86	211859	1.6-2.6	1.0
27	9-20-86	205232	1.9-4.7	2.8
			MEDIAN-	1.7

5.0 PRECURSOR FEATURES DETECTED ON INDIVIDUAL CASES

Table 4 contains precursors detected on individual PPI tilts. The frequency of occurrence for upper-level divergence may be biased downward by the scan strategy employed in 1985 and 1986. At least one precursor was detected in over 90% of the microbursts. Rotation is the most persistent feature i.e., it was detected on the greatest number of tilts. The importance of individual precursors is magnified when examining the null cases (Table 5). Only 2 had a descending core, while 1 contained evidence of mid-level rotation and convergence. The maximum reflectivity peaked at a lower level in the null cases versus those storms which produced microbursts. These results tend to suggest that the precursors evaluated here are not typically present in non microburst-producing storms in the Huntsville area. This is relevant to a TDWR precursor algorithm since the inclusion of features such as rotation, convergence, and a descending reflectivity core should not lead to spurious false alarms.

5.1 Precursor Intensity

The relationship of precursor feature intensity and microburst outflow intensity will be examined to determine if the magnitude of the wind shear can be predicted in advance. Figure 2 is a scattergram of surface divergence and convergence aloft for 22 Huntsville microbursts. There is some correlation (Pearson $r = 0.43$) between the strength of mid-level convergence and the microburst. In general, the weaker events are associated with weaker convergence and stronger events with stronger convergence. However there is quite a lot of variability from a linear relationship. Some of the deviation is related to mass continuity constraints since the areal extent of each feature was not considered. A more consistent pattern might occur if the depth and width of the precursor is compared to the depth and width of the microburst.

A recent study in Oklahoma (Eilts 1987) reported a correlation between the intensity of convergence and surface divergence. In the Oklahoma cases, the strength of convergence exceed that of the outflow. This is different from Huntsville shears where surface divergence is generally stronger (Figure 2). More events will be analyzed to determine if the radial convergence value is related to the strength of the outflow.

Table 4. Number of precursor features detected on individual tilts for microburst producing storms.

Date/Case #	# of Rotation Detections	# of Convergence Detections	# of Divergent Top Detections
06 JUL 86/2	1	0	1
21 SEP 86/4	2	1	1
21 SEP 86/3	2	0	0
24 AUG 85/1	5	0	0
25 JUL 86/3	0	1	0
25 JUL 86/4	1	0	0
25 JUL 86/7	2	0	0
31 JUL 86/7	1	1	0
11 JUL 86/2	0	0	1
21 SEP 86/1	1	0	2
31 JUL 86/5	10	0	0
31 JUL 86/6	0	4	0
21 SEP 86/2	0	1	0
11 JUL 86/4	1	0	2
24 AUG 86/1	7	0	1
24 AUG 86/5	0	9	2
31 JUL 86/2	0	4	0
31 JUL 86/1	0	4	1
25 JUL 86/6	1	2	1
24 AUG 86/2	14	0	0
24 AUG 86/3	0	0	1
06 JUL 86/1	2	0	1
25 JUL 86/2	1	0	2
25 JUL 86/1	2	0	0
20 SEP 86/1	11	6	0
07 AUG 86/1	3	1	0
07 AUG 86/2	3	0	0
TOTAL-	70	34	16

Table 5. Statistics on Huntsville storms which did not produce microbursts.

Date	Time gmt	Max dBz	Rot.	Conv.	Descending core
11 JulA	1653	60	N	N	N
11 JulB	1659	46	N	N	N
11 JulC	1709	60	N	N	N
31 JulA	1754	56	Y	Y	N
31 JulB	1723	60	N	N	Y
24 AugA	1853	53	N	N	N
24 AugB	1932	53	N	N	N
24 AugC	1936	53	N	N	N
24 AugD	1945	52	N	N	N
24 AugE	1915	55	N	N	N
24 AugF	1910	60	N	N	N
24 AugG	1910	40	N	N	N
24 AugH	1901	52	N	N	N
24 AugI	1901	50	N	N	N
24 AugJ	1905	56	N	N	N
24 AugK	1901	53	N	N	N
24 AugL	1817	52	N	N	N
24 AugM	1749	50	N	N	N
24 AugN	1756	50	N	N	N
24 AugO	1817	56	N	N	N
24 AugP	1821	42	N	N	N
24 AugQ	1829	50	N	N	N
24 AugR	1821	57	N	N	Y

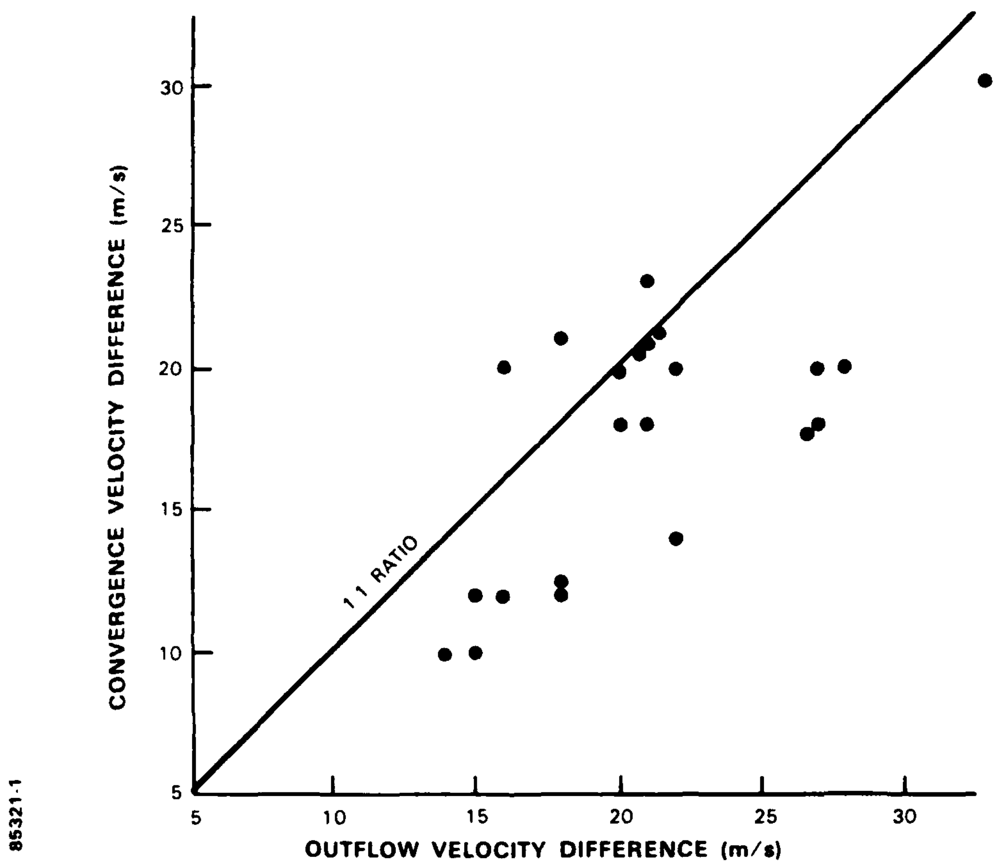

Fig. 2. Scattergram of convergence and surface outflow (m/s).

6.0 WARNING TIME

As shown in Table 6, the median warning times varied from 12 min for a descending core to 0 min for convergence and divergent tops. Mid-level rotation had a median lead time of 4 min. The maximum storm reflectivity peaked 9 min before initial divergence. In terms of cell development this could represent the transition to the decaying stage.

In Table 7, the median warning times for the 1st, 2nd, and 3rd precursor detection were 7.0, 4.0, and 1.0 min respectively. A warning issued on the second detection of a precursor feature should provide ample lead time in most cases and fewer false alarms. There will always be some weak outflows without any precursor. In addition, a feature could have been present as much as 4 min earlier due to the slow volume scan update time.

Table 6. Average warning times for precursor features.

Date/Event #	Rot. min	Con. min	Des. Core min	Max dBz min	Div Tops min
24 Aug. 85/1	8	0	-	-	-
06 July 86/1	6	0	12	12	4
06 July 86/2	4	0	17	17	10
06 July 86/3	0	0	12	12	-
11 July 86/2	0	0	15	9	9
11 July 86/3	0	0	17	17	-
11 July 86/4	7	0	14	19	16
11 July 86/5	0	0	8	8	0
25 July 86/1	4	5	19	13	-
25 July 86/2	15	0	31	10	21
25 July 86/3	0	5	11	11	0
25 July 86/4	7	0	13	10	0
25 July 86/5	0	0	9	9	0
25 July 86/6	6	5	11	0	4
25 July 86/7	7	0	12	12	0
31 July 86/1	0	3	18	1	2
31 July 86/2	0	4	6	-	-
31 July 86/3	0	0	14	30	0
31 July 86/4	0	0	16	6	-
31 July 86/5	26	0	29	13	0
31 July 86/6	0	9	9	-	0
31 July 86/7	2	7	8	9	0
07 Aug. 86/1	5	8	7	7	0
07 Aug. 86/2	8	0	10	0	-
24 Aug. 86/1	24	18	12	5	5
20 Sep. 86/1	14	8	11	3	0
21 Sep. 86/1	2	0	12	6	14
MEDIAN-	4	0	12	9	0

Table 7. Warning times for the 1st, 2nd, and 3rd precursor detection.

Date/Case #	1st Detection min	2nd Detection min	3rd Detection min
09 SEP 86/1	14	12	10
24 AUG 86/2	14	13	13
24 AUG 86/3	0	0	0
06 JUL 86/1	6	4	2
11 JUL 86/5	0	0	0
25 JUL 86/2	21	15	9
25 JUL 86/1	9	5	0
07 AUG 86/2	8	7	4
31 JUL 86/3	0	0	0
31 JUL 86/2	7	4	2
25 JUL 86/6	6	5	4
31 JUL 86/1	6	3	2
24 AUG 86/5	18	16	15
24 AUG 86/1	18	12	10
11 JUL 86/4	16	13	7
11 JUL 86/3	0	0	0
21 SEP 86/2	1	0	0
31 JUL 86/6	9	8	7
31 JUL 86/5	26	25	10
21 SEP 86/1	14	3	1
31 JUL 86/4	0	0	0
11 JUL 86/2	10	0	0
06 JUL 86/3	0	0	0
31 JUL 86/7	7	2	0
25 JUL 86/7	7	6	0
25 JUL 86/4	6	0	0
25 JUL 86/5	0	0	0
25 JUL 86/3	5	1	0
24 AUG 85/1	8	7	6
21 SEP 86/3	22	7	4
21 SEP 86/4	10	9	7
06 JUL 86/2	11	4	0
24 AUG 86/4	0	0	0
MEDIAN -	7	4	1

7.0 ADDITIONAL WET MICROBURST CRITERIA

In order to distinguish a microburst-producing cell, the following criteria is proposed based on the 34 Huntsville cases discussed here:

1) maximum reflectivity of 54 dBz or greater,
2) core (>50 dBz) depth of 5.2 km, and
3) maximum reflectivity is attained on 3 volume scans.

These thresholds were tested against 23 null events and only one satisfied the criteria without producing a windshear. In that case, an outflow could have gone undetected due to the beam height at a distance of 45 km. Preliminary results indicate the above criteria could serve as a guideline to a potential microburst cell in the southeastern U.S. The utility of these particular features and thresholds will be tested on the wet microburst storms from Denver.

8.0 7 AUGUST 1986 EVENT

On 7 August 1986, a cluster of thunderstorms produced a line microburst to the north of FL-2. Table 8 is a list of precursor times for one of the events. All precursor features were detected at least 5 min before the initial surface divergence. The average lead time was 10 min. This should provide ample warning to ATC and pilots. Unfortunately, not all microbursts contain precursor information like the 7 August event. Figure 3 is a time-intensity profile of velocity features. Convergence provides no clue to the strengthening of the outflow, while rotation peaks at the same time as the microburst shear. In this case-study, the intensity of surface divergence was proportional to the strength of rotation.

Table 8. List of radar detectable precursors on 7 August 1986 microburst

Criteria	Minutes Before Event
54 dBz	27
54 dBz on 3 scans	15
Convergence	8
Core depth of 5.2 km	7
Descending Core	7
Maximum dBz	7
Rotation	5

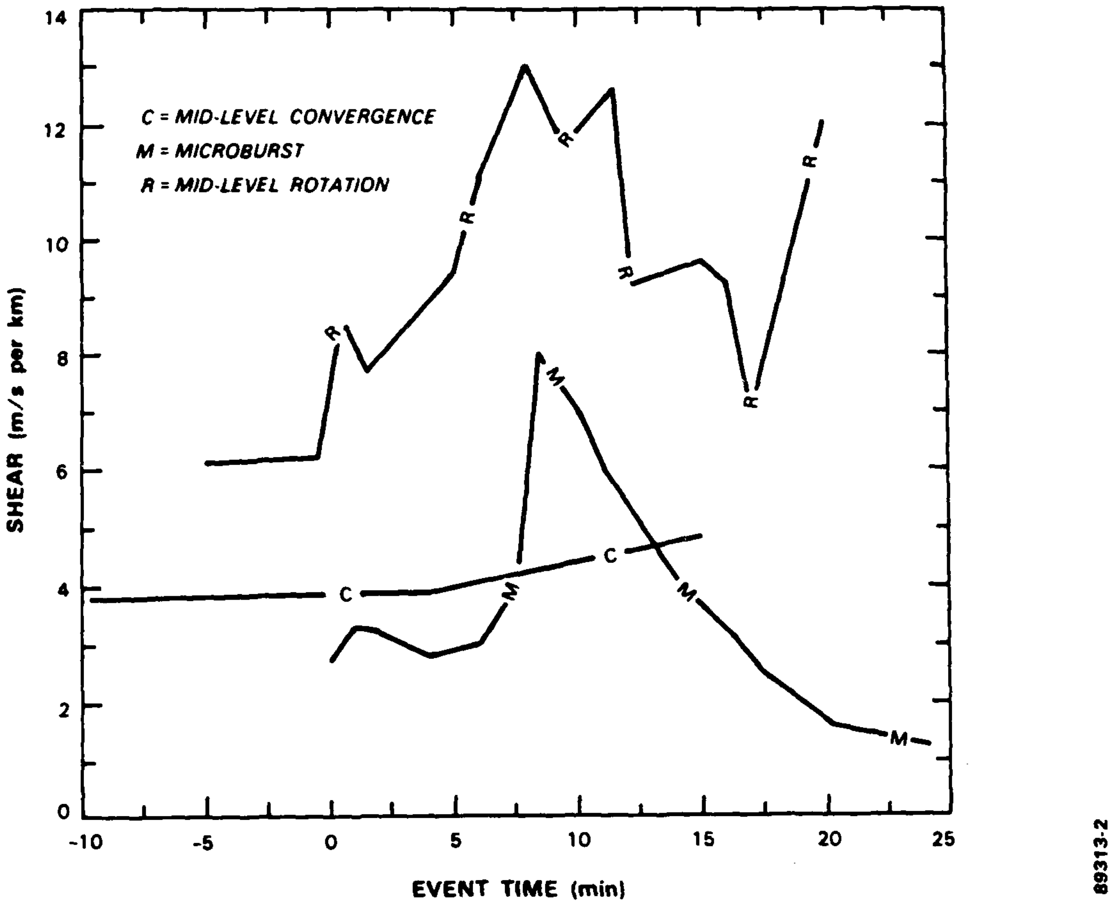

Fig. 3. Time-height profile of intensity vs time.

9.0 SUMMARY AND CONCLUSION

This study has considered the significance of features aloft in providing advanced warning of potential microburst shears in the southeast U.S. In summary, a southeastern U.S. microburst detection algorithm should include upper-altitude features such as rotation, convergence, and a descending reflectivity core. In order to detect upper-level divergence, the radar must scan to the top of the echo. Based on the cases considered in this report, divergent tops could be a useful downburst precursor.

An alarm issued the second time a precursor is detected appeared to yield a 5-min lead time prior to the initial outflow. Allowing for a second detection before issuing a warning should produce fewer false alarms. One issue that was not fully evaluated in this report is the variability in warning times prior to a microburst outflow. Thus a microburst detection algorithm should consider all the possible precursors and not focus on an individual feature.

The data reported here was obtained by the FL-2 Doppler radar operating in an RHI and PPI mode. While the FL-2 radar has moved to Denver for the 1987 TDWR testing, there are still active precursor measurements being conducted in Huntsville with the MIT C-band Doppler radar. The MIT radar primarily scans a PPI sequence until an outflow is detected and then shifts to a PPI/RHI mixture. Unfortunately, system scanning limitations require a coarser vertical resolution than the FL-2 1986 scan strategy.

The regional variability in precursors must be included in future algorithm versions. In this respect, it is important to determine whether the qualitative and quantitative observations made in this study are generally applicable. Previous studies in Denver and Oklahoma noted that mid-level rotation and convergence as well as a descending core often precede a microburst. However, the scan strategy used made it difficult to develop statistics on an adequate number of cases.

One of the advantages of the 1987 FAA Doppler weather radar testing in Denver versus earlier projects (JAWS and CLAWS) is the: A) rapid surface update rate of 1 min, B) 1 km vertical resolution for precursor features, and C) a 2.5 minute update time for scanning the precursor region aloft.

Preliminary results from our 1987 real-time observations in Denver indicate convergence and descending cores are prevalent precursors in microburst storms. A data-set containing both microburst and non-microburst producing storms from Denver will be examined for the presence of the precursors documented in this study.

REFERENCES

Campbell, Steve: 1987, "Terminal Doppler Weather Radar Siting Issues". PROJECT MEMO 43PM-WX-0005, MIT Lincoln Laboratory, Boston, Massachusetts. pp 1-40.

Eilts, M.D., 1987: "Nowcasting Low-Altitude Wind Shear With a Doppler Radar". AIAA 25TH AEROSPACE SCIENCES MEETING, Reno, Nevada. pp 1-5.

Evans, J.E., and D. Johnson, 1984: "The FAA transportable Doppler weather radar". 22nd Conference on Radar Meteorology, Zurich, Switzerland. 246-250.

Fujita, T.T., 1987: "Presentation to MIT Lincoln Laboratory Air-Traffic Surveillance Group". MIT Lincoln Laboratory.

Roberts, R.D., and J.W. Wilson, 1986: "Nowcasting Microburst Events Using Single Doppler Radar Data". 23RD CONFERENCE ON RADAR METEOROLOGY, Snowmass, Colorado. pp 14-17.

Wilson, J.W., and D. Reum, 1986: "The Hail Spike: Reflectivity And Velocity Signature". 23RD CONFERENCE ON RADAR METEOROLOGY, Snowmass, Colorado. pp 62-65.

Wilson, J.W., and R.D. Roberts, 1983: Evaluation Of Doppler Radar For Airport Wind Shear Detection. 21ST CONFERENCE ON RADAR METEOROLOGY, Edmonton, Alberta. pp 616-623.

Wilson, J.W., R.D. Roberts, C. Kessinger, and J. McCarthy, 1984: Microburst Wind Structure and Evaluation of Doppler Radar for Airport Wind Shear Detection. JOURNAL OF CLIMATE AND APPLIED METEOROLOGY, VOLUME 23, 898-914.

Zrnic' D.S., 1987: Three-body scattering produces precipitation signature of special diagnostic value. RADIO SCIENCE, VOLUME 22, 76-86.