19930010416

N93-19605

Session V. Doppler Related Research

Microburst Characteristics Determined from 1988-91 TDWR Testbed Measurements

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MICROBURST CHARACTERISTICS DETERMINED FROM 1988-91 TDWR TESTBED MEASUREMENTS

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15 APRIL 1992

(PRESENTED BY J. EVANS)

Vugraph Text - Biron/Isaminger Papers

Vugraph #1 "Outline"

Under FAA sponsorship, the MIT Lincoln Laboratory has conducted experimental windshear measurements at a number of locations since 1985:

1985:	Memphis, TN
1986:	Huntsville, AL
1987-88:	Denver, CO
1989:	Kansas City, MO
1990-91:	Orlando, FL

The principal sensor was the TDWR testbed radar (S-band with 1° beamwidth through 1990, C-band with 0.5° beamwidth since 1991). Supporting sensors have included the UND C-band Doppler radars (1986-91) the MIT C-band Doppler radar (1991) and a sizable surface mesonet (measuring average and peak temperatures, humidity and winds 1/minute).

This paper presents some recent results (extending those in the paper by Wolfson, et al. at the 19th Conference on Decision and Control) germane to airborne windshear system design and certification. We will first discuss the data analysis procedure and the associated caveats. The relative frequency, severity and duration of microburst hazards at the various locations is important for determining the tradeoffs between safety and operational impact of false alerts which are encompassed in detection system thresholds.

We next consider radar/lidar design issues such as reflective in microbursts and the vertical structure of outflows. A companion topic, gust front characteristics, is discussed in a paper by Klingle, et al. at the vugraphs end of this talk. Finally, we provide recent surface thermodynamic data associated with microbursts.

OUTLINE

- ANALYSIS PROCEDURE/CAVEATS
- NUMBER OF EVENTS
- HAZARD LEVELS AND DURATIONS
- RADAR/LIDAR DESIGN FACTORS
  - REFLECTIVITIES
  - SIZES
- THERMODYNAMICS
- SUMMARY

Vugraph #3 "Assessment Procedure"

The TDWR testbed radar meteorologists have compiled gross microburst structure information on a large number of the microbursts. The meteorologist inspects the TDWR surface scan radial velocity field with the TDWR microburst detection algorithm overlaid on the image. The meteorologist clicks the mouse on the radial velocity image pixels characterizing the maximum and minimum velocity associated with a microburst as well as the midpoint. The velocity values, locations and corresponding reflectivity values are stored in a computer data base. The shear is estimated by the equation $S = \Delta V / \Delta R$ where ΔV is the velocity difference and ΔR (i.e.., the "width") the distance between maxima and minimum velocities.

Thus, localized high shear regions such as discussed by Campbell and Proctor in this conference are not captured by this approach, (i.e., the shears computed generally are a lower bound to shear averaged over typical distances such as 1-2 km).

Since only horizontal velocities are considered, and the degree asymmetry is not known, the vertical component is not directly considered. It should also be noted (see Campbell paper in this conference) that the altitude at which the surface tilt measured may have biased velocities downward. The data base considers microbursts at ranges out to at least 30 km and, one expects (from geometrical arguments) that the bulk of the data is a relatively long range where horizon effects tend to create a beam volume at higher altitude.

In some cases, we have high resolution vertical profiles from RHI scanning on microbursts at close range. The 1991 data is particularly useful in this respect due to the 0.5° beamwidth.

ASSESSMENT PROCEDURE

- EXPERIENCED RADAR METEOROLOGIST ASSESSMENT OF MICROBURST OUTFLOWS AND CORES AIDED BY TDWR MICROBURST ALGORITHM PRODUCT OUTPUT
- RESULTS STORED IN COMPUTER DATA BASE FOR SUBSEQUENT ANALYSES
- CAVEATS:

  SHEAR ESTIMATES REPRESENT AVERAGE OVER OUTFLOW REGION- LOCALIZED "HOT SPOTS" NOT CONSIDERED

  ASYMMETRY NOT CONSIDERED-WOULD AFFECT VERTICAL VELOCITY ESTIMATES FROM HORIZONTAL DIVERGENCE

  OUTFLOW ALTITUDE ESTIMATES SIGNIFICANTLY EFFECTED BY 3 D SCAN PATTERN USED AND DISTANCE TO OUTFLOW- MOST ACCURATE RESULTS WITH RHI'S USED IN KC AND ORL

Vugraph #4 "Dist. of MB Strength"

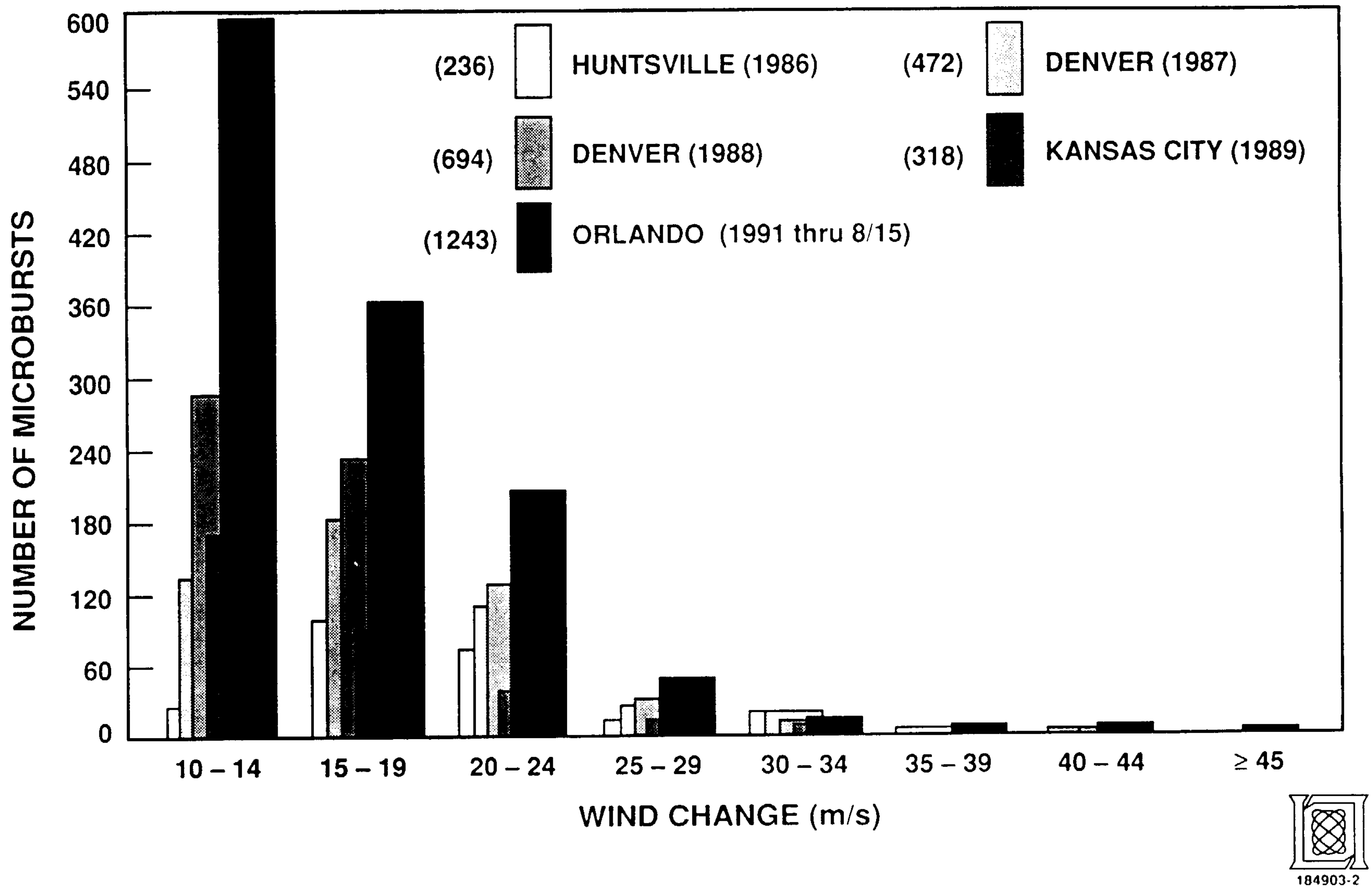
The number of microbursts detected in real time (shown in parentheses next to the bar code) varies considerably between the various locations. The Huntsville results were biased low (by a factor of approximately 2) by lack of real time automatic detection algorithm outputs. The Kansas City data reflects a year with far fewer thunderstorms than normal. Orlando was clearly the most active location with a total of over 1600 microbursts observed through October 1991.

The next three vugraphs show the observed ΔV ΔR converted the F factor estimates using the equation

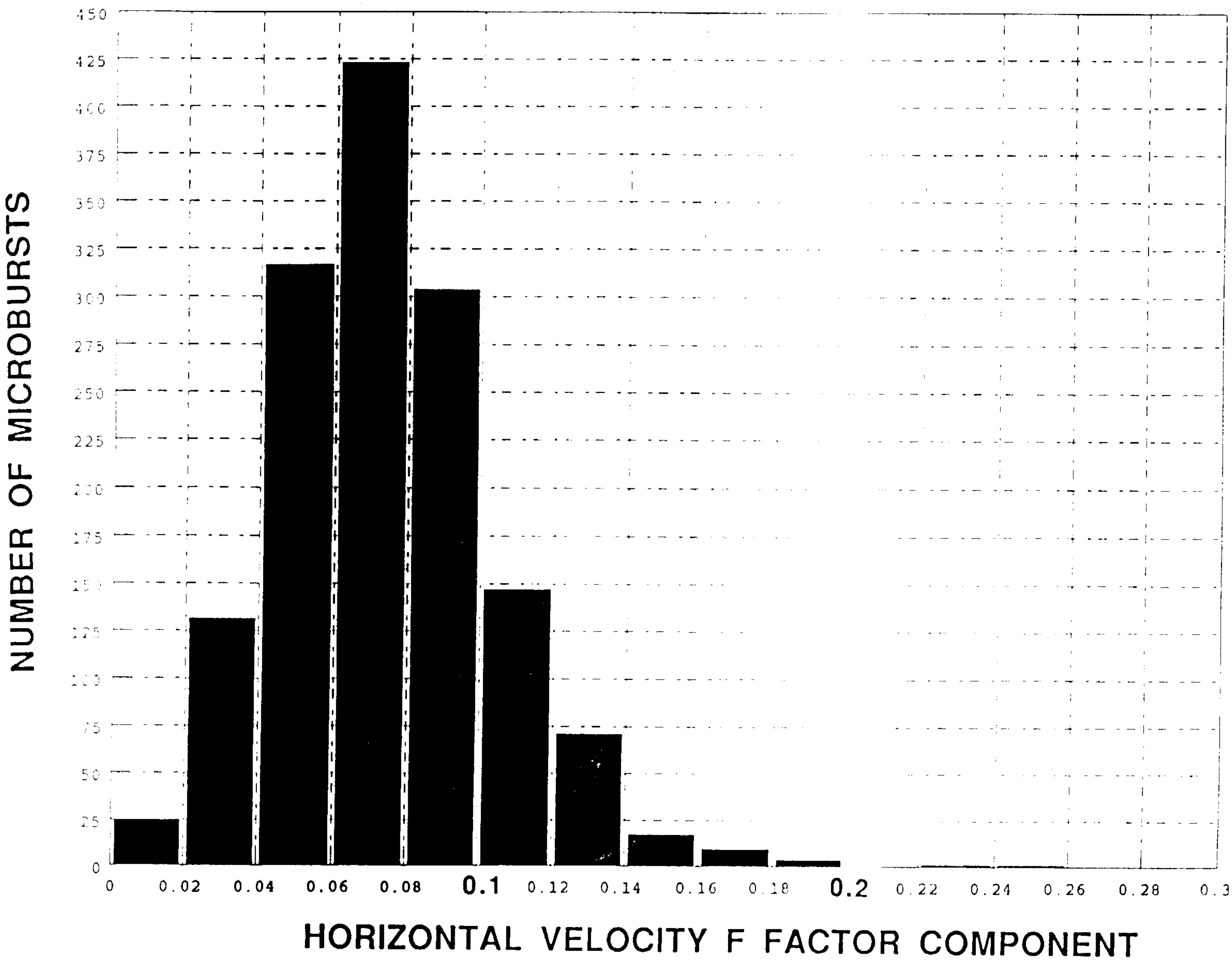
$$F = K^{*}\Delta V / \Delta R$$

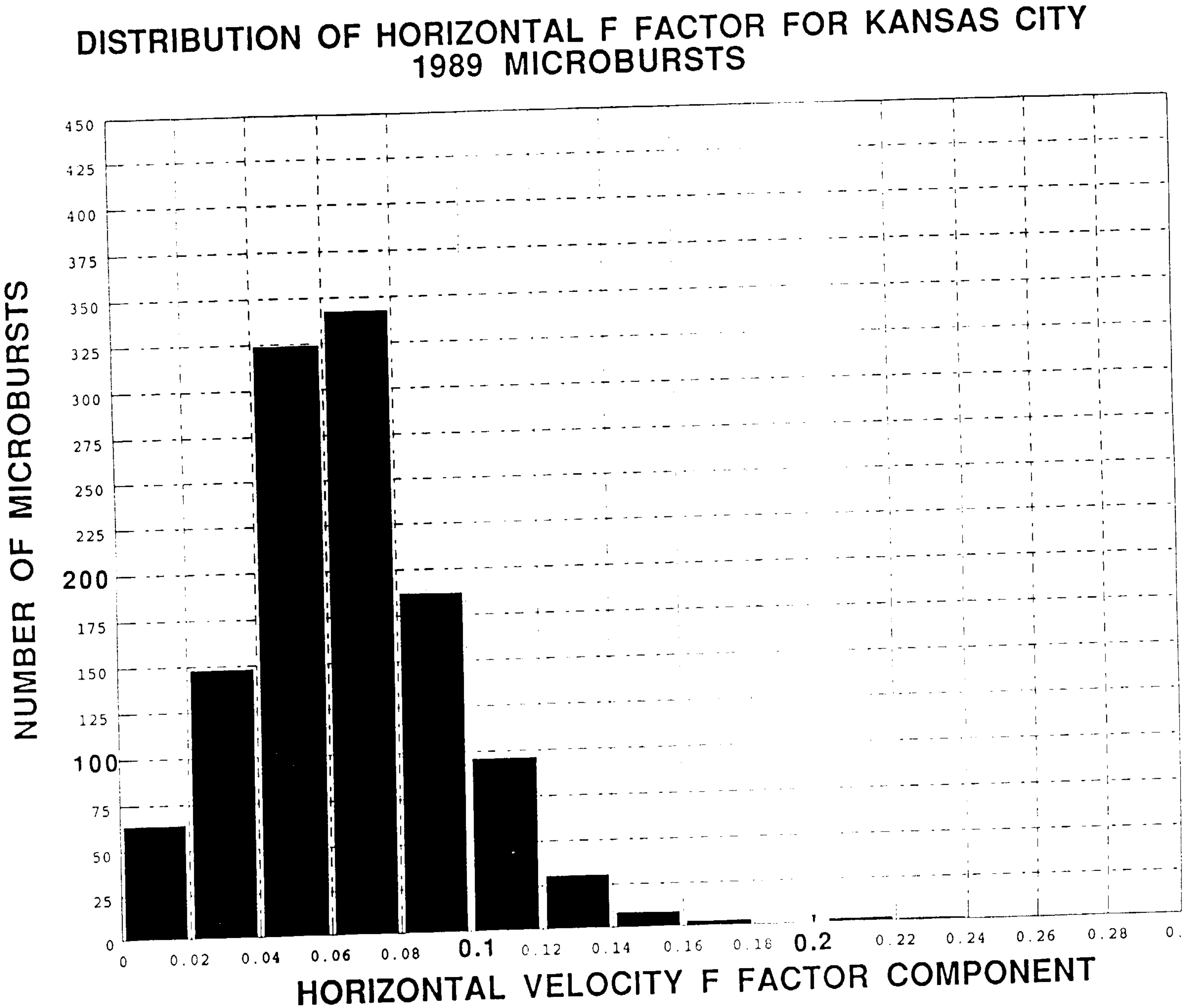
corresponding to a flight at a ground speed of approximately 130 knots. We see that all locations have at least 100 such events with Orlando having over 300 such events in 1991.

DISTRIBUTION OF MICROBURST STRENGTHS



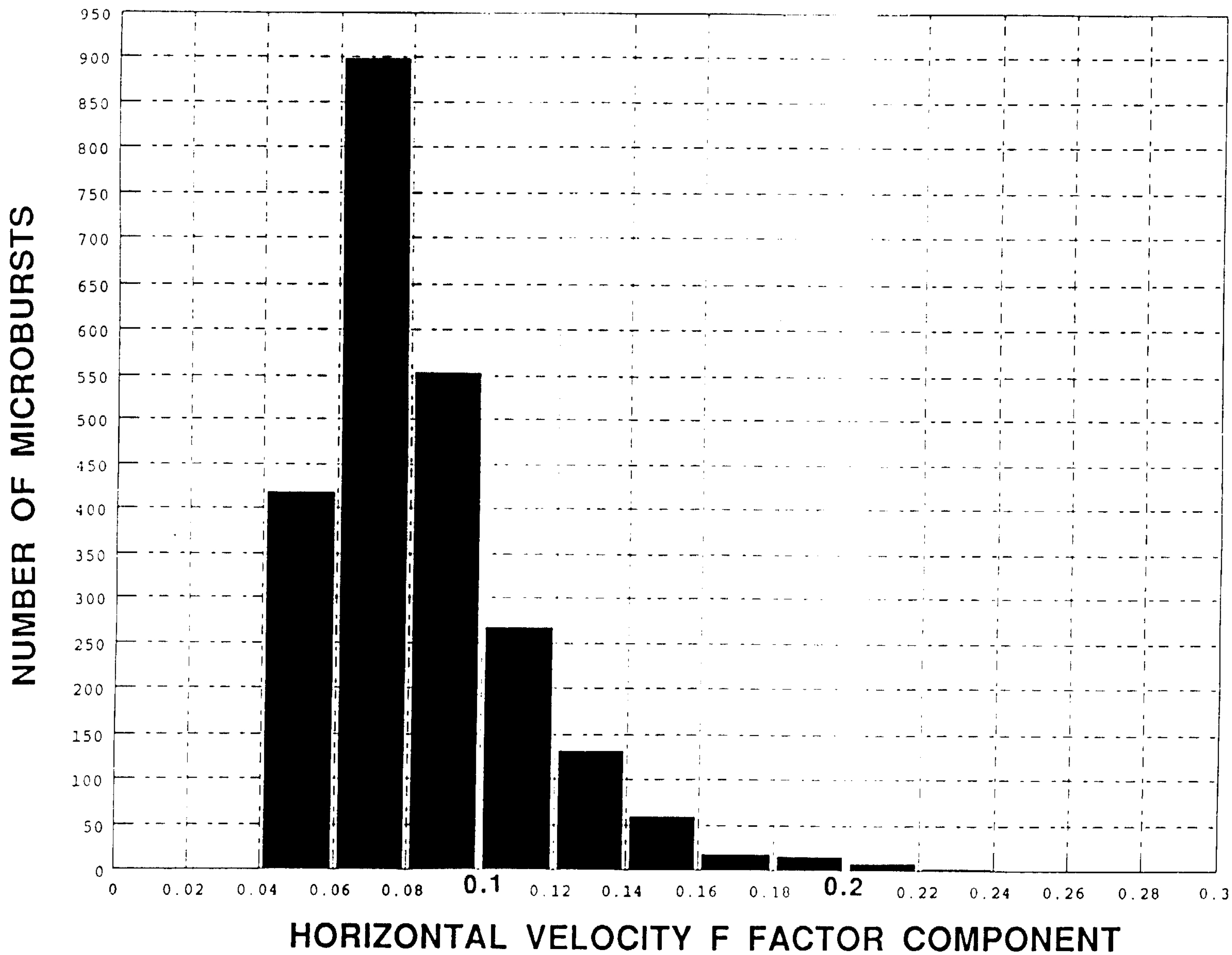
DISTRIBUTION OF HORIZONTAL F FACTOR FOR DENVER 1988 MICROBURSTS





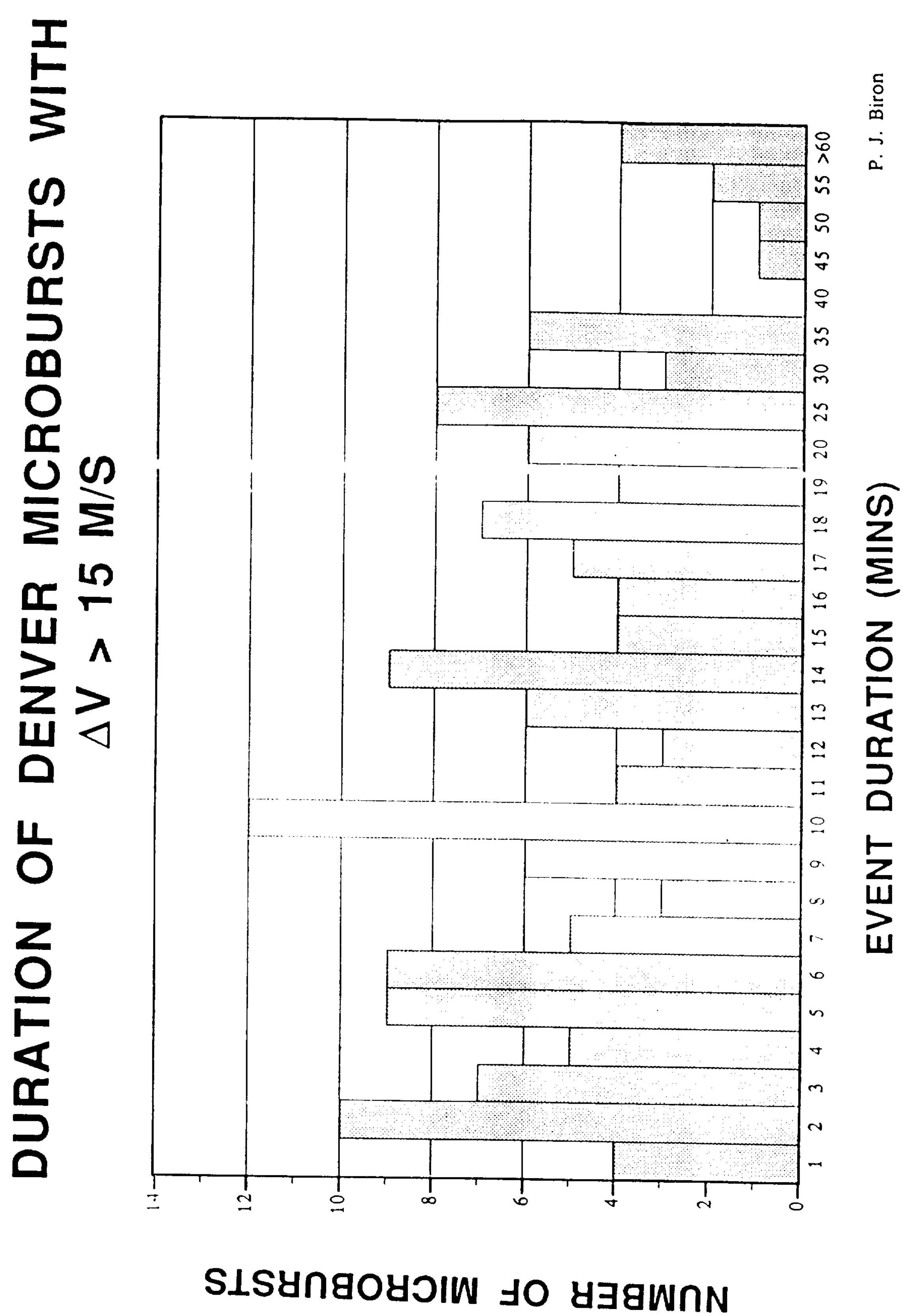
DISTRIBUTION OF HORIZONTAL F FACTOR FOR KANSAS CITY
1989 MICROBURSTS
NUMBER OF MICROBURSTS
450
425
400
375
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24
0.26
0.28
0.3
HORIZONTAL VELOCITY F FACTOR COMPONENT

DISTRIBUTION OF HORIZONTAL F FACTOR FOR ORLANDO 1991

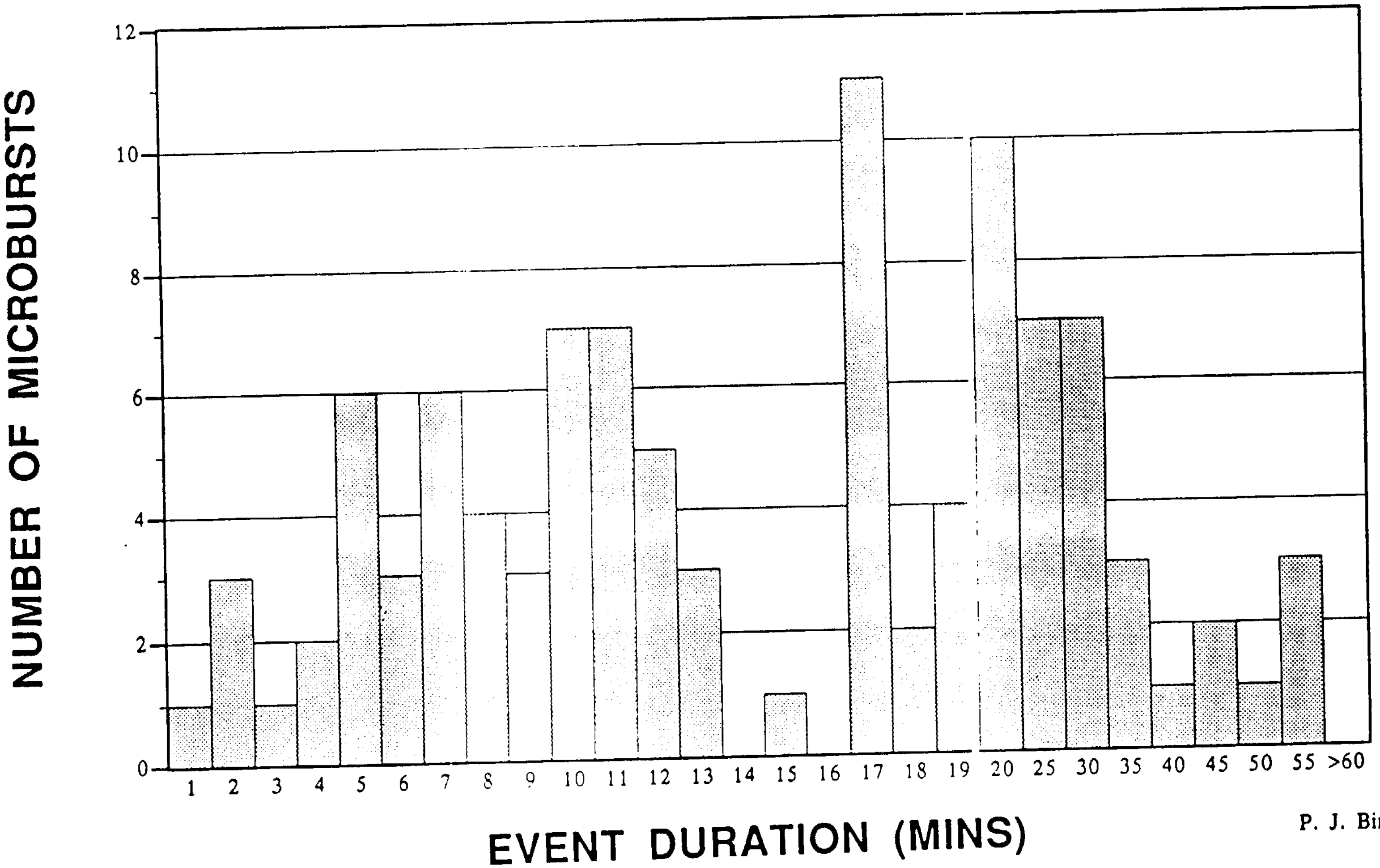


Vugraphs 7 - 8 "Duration of MB..."

The Denver microbursts are seen to have almost an uniform distribution of duration out to 35 minutes duration. By contrast, Orlando appears to have a bimodal distribution with modes centered at durations 8 minutes and 20 minutes respectively.


DURATION OF DENVER MICROBURSTS WITH
ΔV > 15 M/S
NUMBER OF MICROBURSTS
EVENT DURATION (MINS)
0
2
4
6
8
10
12
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 25 30 35 40 45 50 55 >60
P. J. Biron

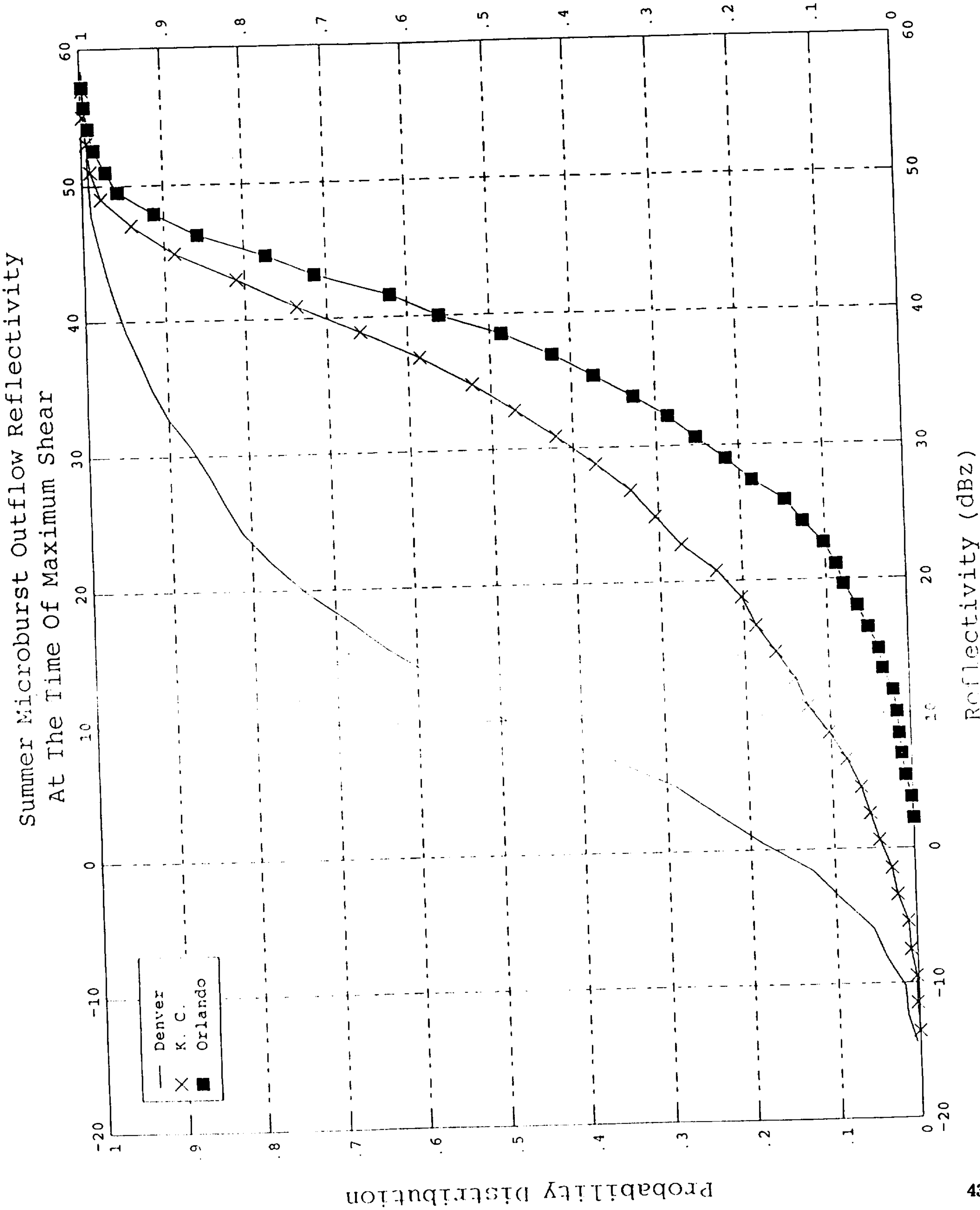
DURATION OF ORLANDO MICROBURSTS WITH $\Delta V > 15$ M/S



P. J. Biron

Vugraph #9

The range in outflow reflectivities at the velocity maxima and minima at individual locations vary 40-50 dB. Denver is seen to have a median reflectivity of 10 dBZ which is some 25 dB lower than Kansas City or Orlando. For a single microburst, the outflow reflectivities can differ by some 35 dB. This typically occurs when a microburst downdraft that initially was in the middle of a heavy rain region migrates to the edge of the rain region so that one portion of the microburst outflow is in a region of little or no rain. It should be noted that detection of the low reflectivity region will be very difficult for Doppler radars which have extended range sidelobes (e.g., due to the use of pulse compression). Note also that a significant fraction of the Denver microbursts have reflectivity less than 0 dBZ (the TDWR testbed has a sensitivity of approximately -5 dBZ at a range of 50 km).


Summer Microburst Outflow Reflectivity
At The Time Of Maximum Shear
Denver
K. C.
Orlando
Reflectivity (dBz)
Probability Distribution
-20
-10
0
10
20
30
40
50
60
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1

Vugraph #10 "Summer MB Maximum Reflectivity"

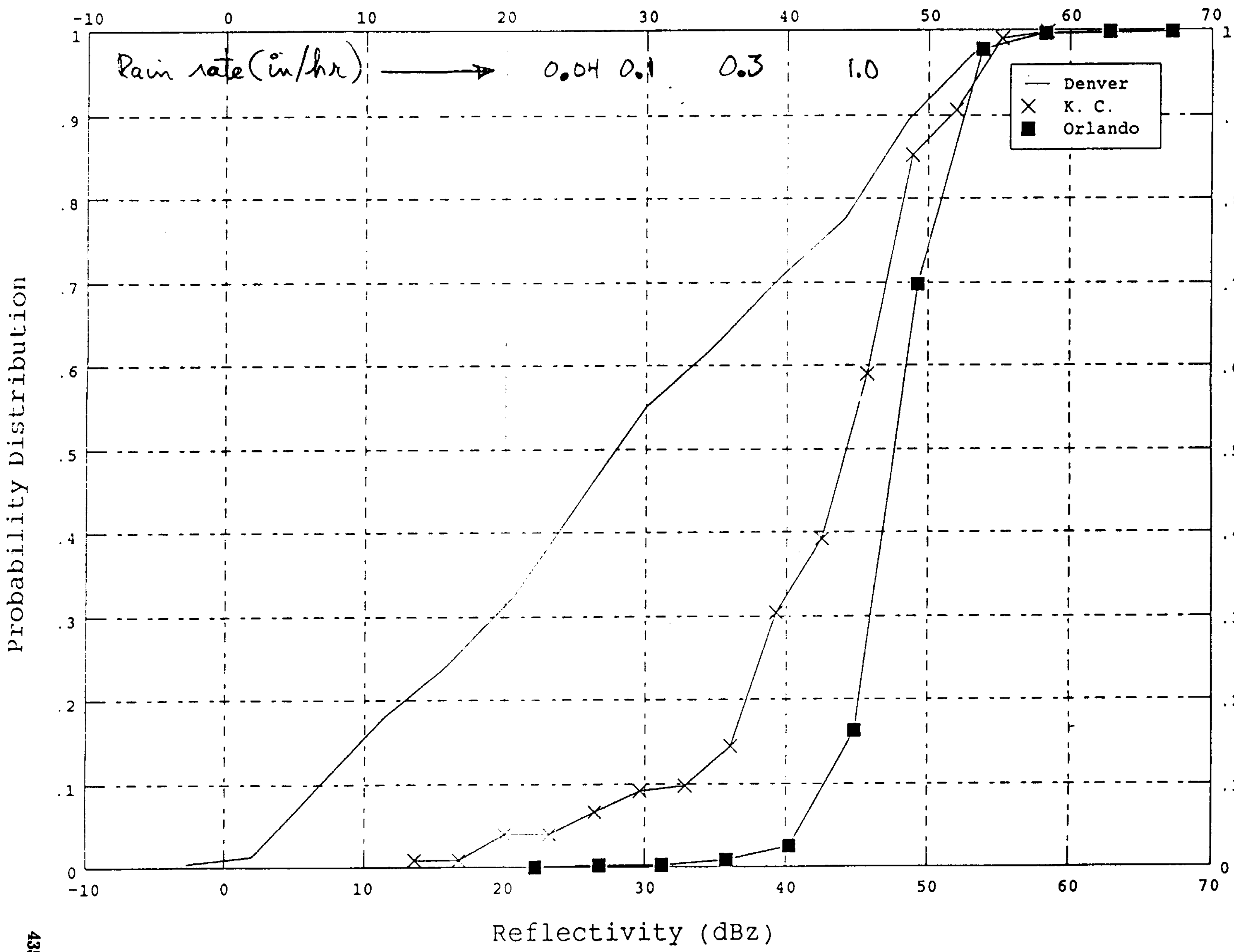
The core reflectivities are seen to be higher (e.g., by 10 - 15 dB for median levels) than the outflow reflectivities. Note also that the range of core reflectivities is much less than the outflow reflectivity. Most of the literature to date has focused on core reflectivities. Thus, although most microbursts in Orlando are very wet, (nearly all core reflectivities > 40 dBZ), over 10% of the outflows are fairly dry (< 20 dBZ).

The rain rates shown at the top of the figure were computed from the relationship

$$Z = 295\, R^{1.43}$$

where R is the rainfall rate in mm/hr and Z is the reflectivity factor in mm^6/m^3. Note: the rain rates sketched in on the corresponding vugraphs during the verbal presentation were erroneously labeled as inches/hr, but were actually mm/hr. At the meeting, the threshold of rain that would raise concerns about attenuation for laser systems was stated to be about 1 inch/hour. We see that approximately half of the Orlando microbursts will have rain rates exceeding 1 inch/hour. Thus, Orlando testing will be useful in addressing the ability of laser systems to work in heavy precipitation.

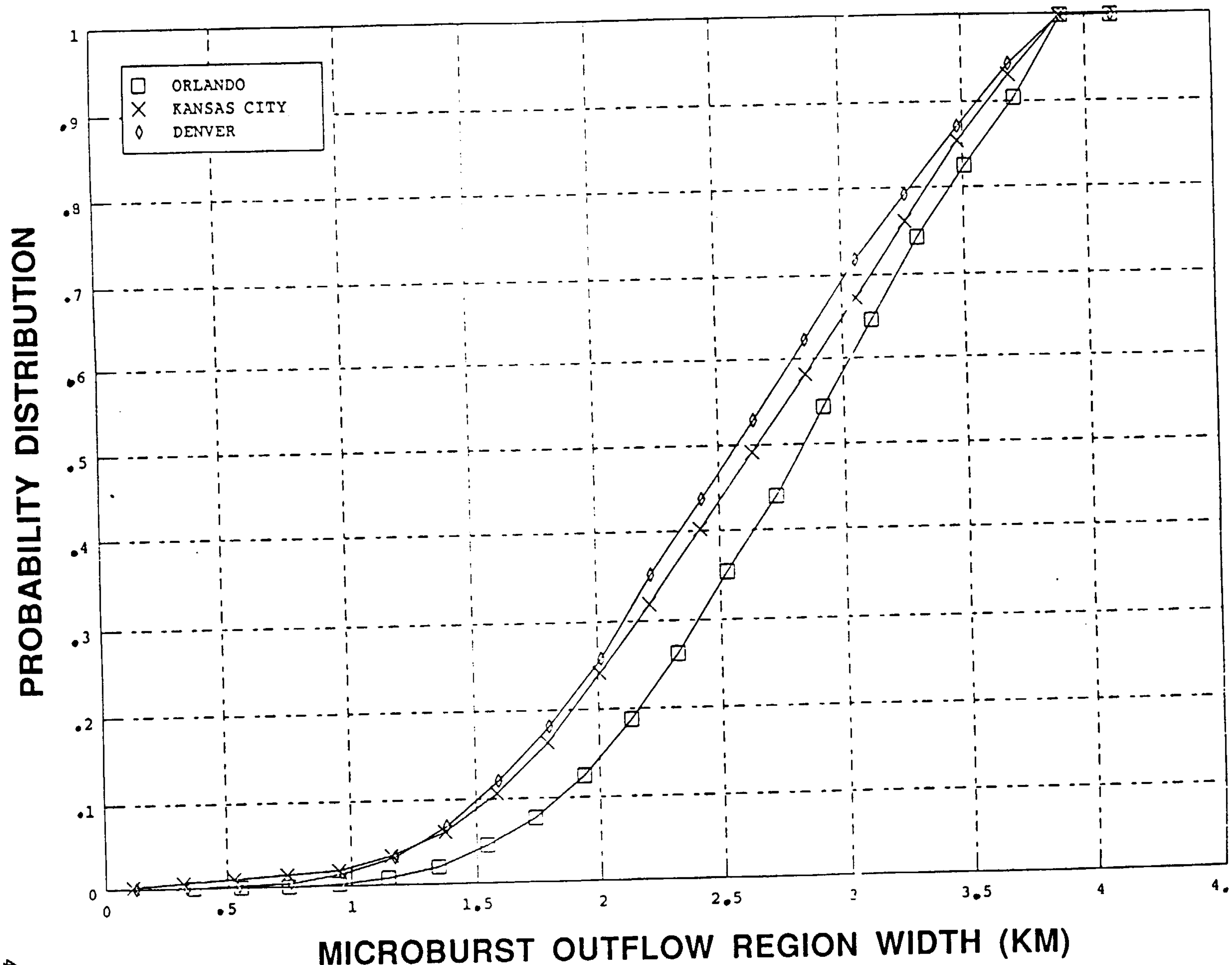
Summer Microburst Maximum Reflectivity



Vugraph #11 "MB Outflow Region Widths"

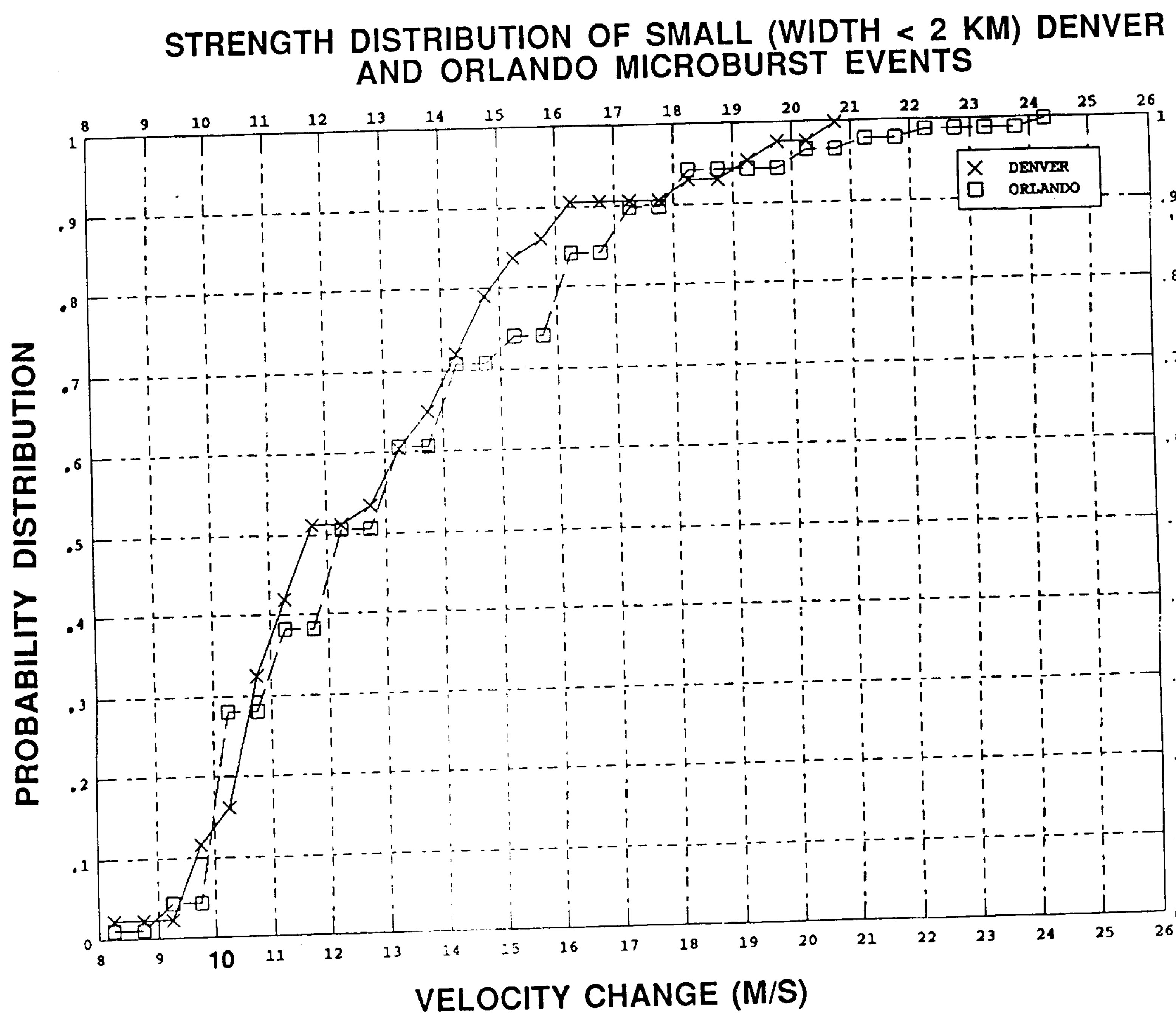
The spatial scale of microburst outflows is important for design of spatial filtering algorithms. The outflow size is seen to be quite similar with Orlando having slightly larger widths. A number of outflows are less than 1 nmi wide.

MICROBURST OUTFLOW REGION WIDTHS



Vugraph #12 "Strength Distribution...

Since small events pose a difficult detection challenge, the magnitude of the wind changes associated with these is of concern. We see that the bulk (i.e., 70%) of these correspond to a wind change of less than 30 knots. However, there are some strong (> 40 knot) small events.


STRENGTH DISTRIBUTION OF SMALL (WIDTH < 2 KM) DENVER AND ORLANDO MICROBURST EVENTS
PROBABILITY DISTRIBUTION
VELOCITY CHANGE (M/S)
DENVER
ORLANDO

Vugraph #13 - 15 "Vertical Structure of Orlando MB"

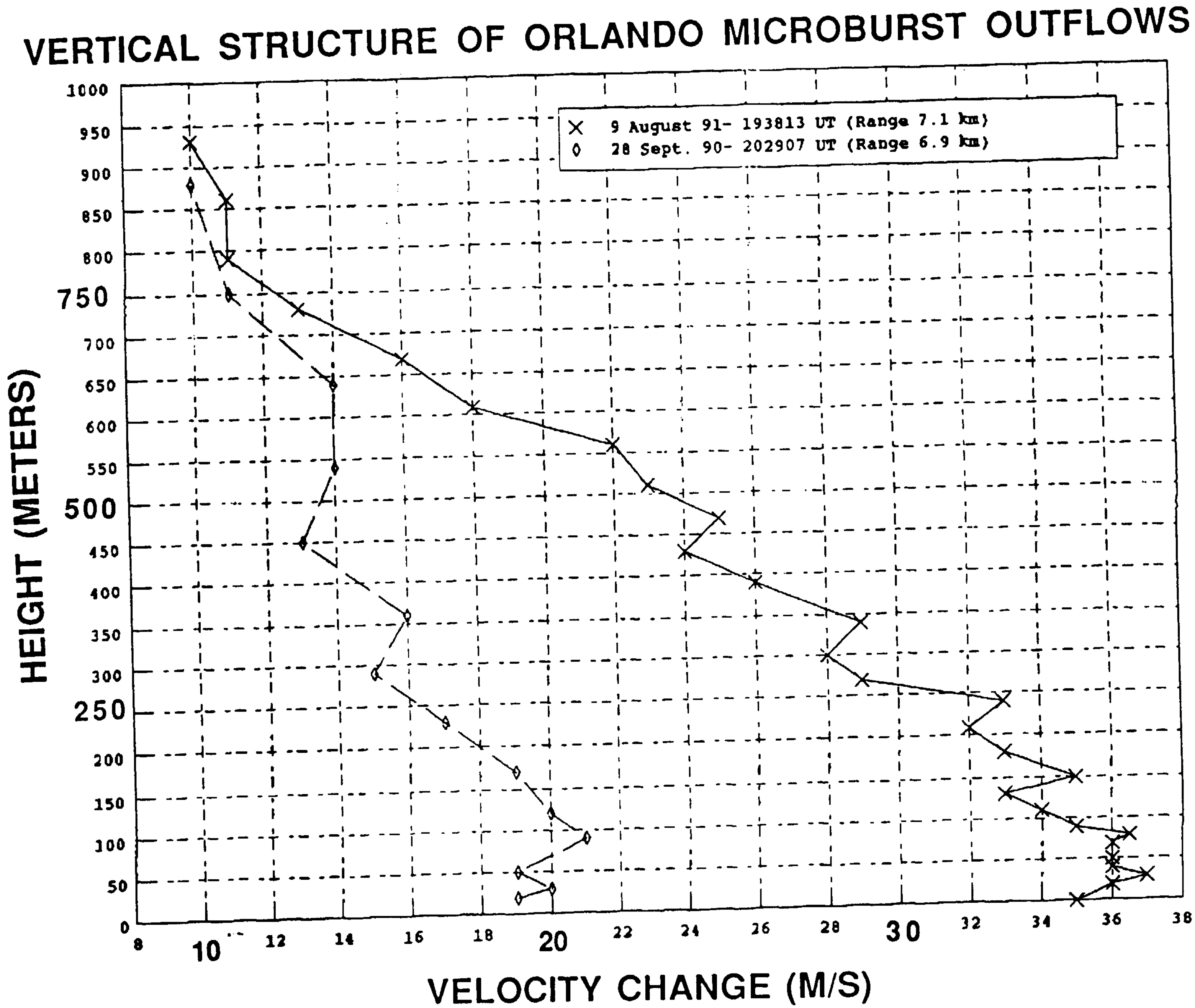
The vertical structure of microburst events is a key issue in forward looking sensor design. The bulk of the reported results on vertical profiles have been flawed by the prior vertical resolution associated with:

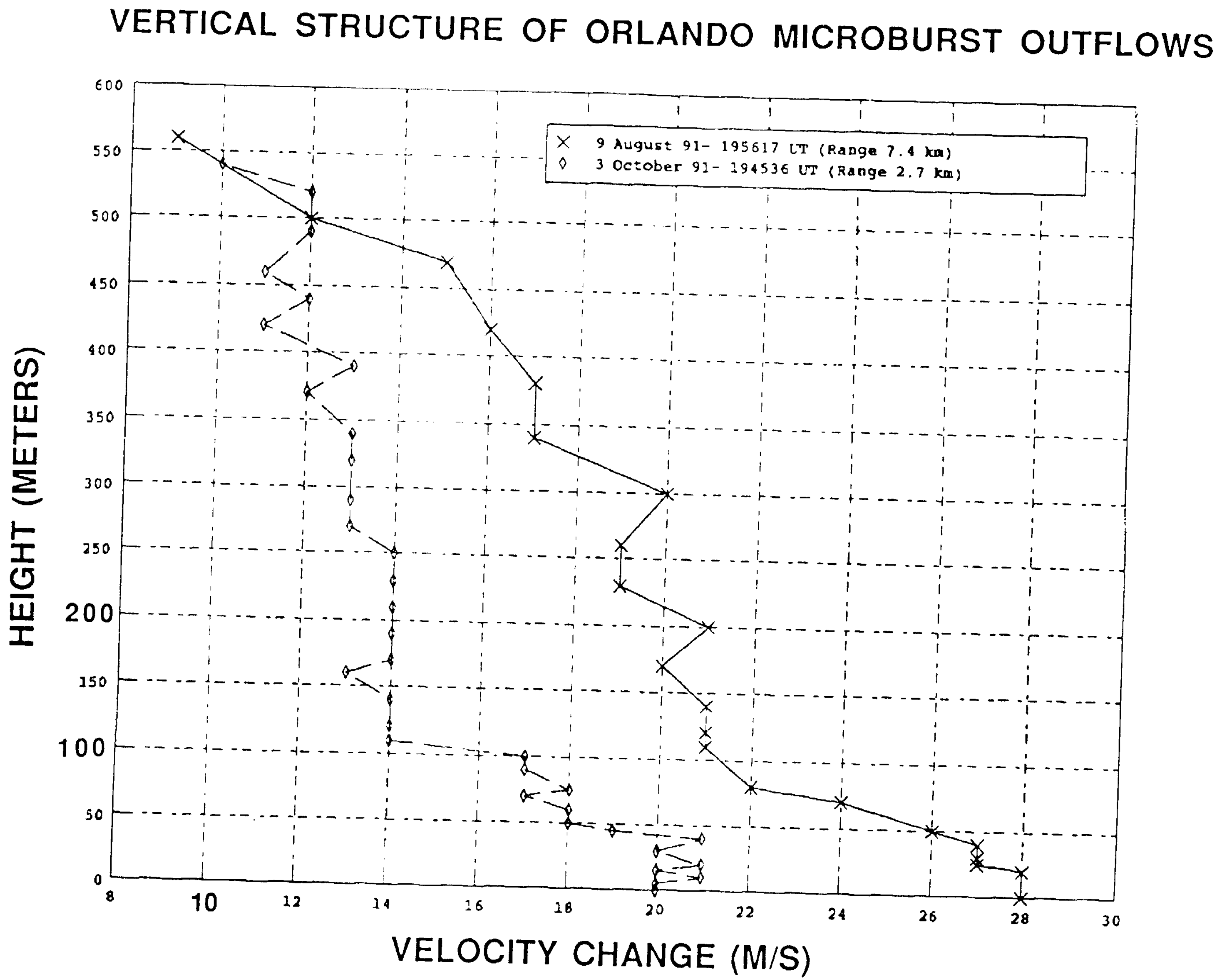
1) the use of PPI scans with relatively widely spaced elevation angles and/or

2) the inclusion of data from long ranges where the radar beam vertical extent is large relative to the microburst variation with height.

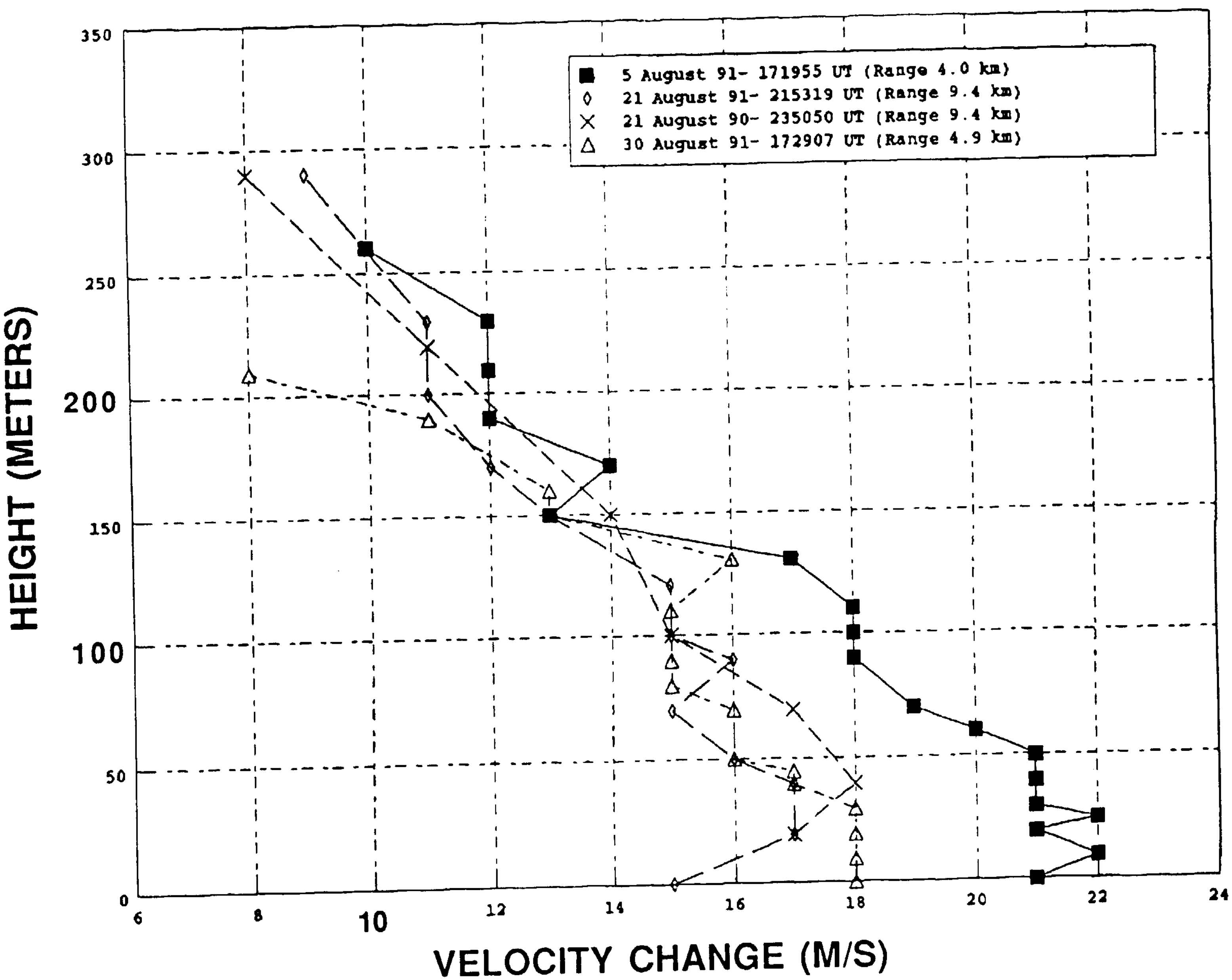
In Orlando, we are attempting to improve this situation by taking advantage of the narrow beamwidth (0.5°) of the TDWR testbed. Microbursts within 10 km (corresponding to a beamwidth vertical extent < 80m) are scanned using RHI scans to provide closely spaced vertical measurements.

We see a wide variation in vertical profile between events and during an individual event. The drop off in velocity from the surface to 300m AGL is about 6 knots (15-30%) for the 9 August event at 1938 GMT and for the 28 September event. By contrast, we see similar drop off between the surface and 100m AGL for the 3 October event and the 9 August event at 1956 GMT. The August 1991 events show a 33-50% drop off in velocity at 150m AGL.


VERTICAL STRUCTURE OF ORLANDO MICROBURST OUTFLOWS
9 August 91- 193813 UT (Range 7.1 km)
28 Sept. 90- 202907 UT (Range 6.9 km)
HEIGHT (METERS)
VELOCITY CHANGE (M/S)


VERTICAL STRUCTURE OF ORLANDO MICROBURST OUTFLOWS
9 August 91- 195617 UT (Range 7.4 km)
3 October 91- 194536 UT (Range 2.7 km)
HEIGHT (METERS)
0
50
100
150
200
250
300
350
400
450
500
550
600
VELOCITY CHANGE (M/S)
8
10
12
14
16
18
20
22
24
26
28
30

VERTICAL STRUCTURE OF ORLANDO MICROBURST OUTFLOWS

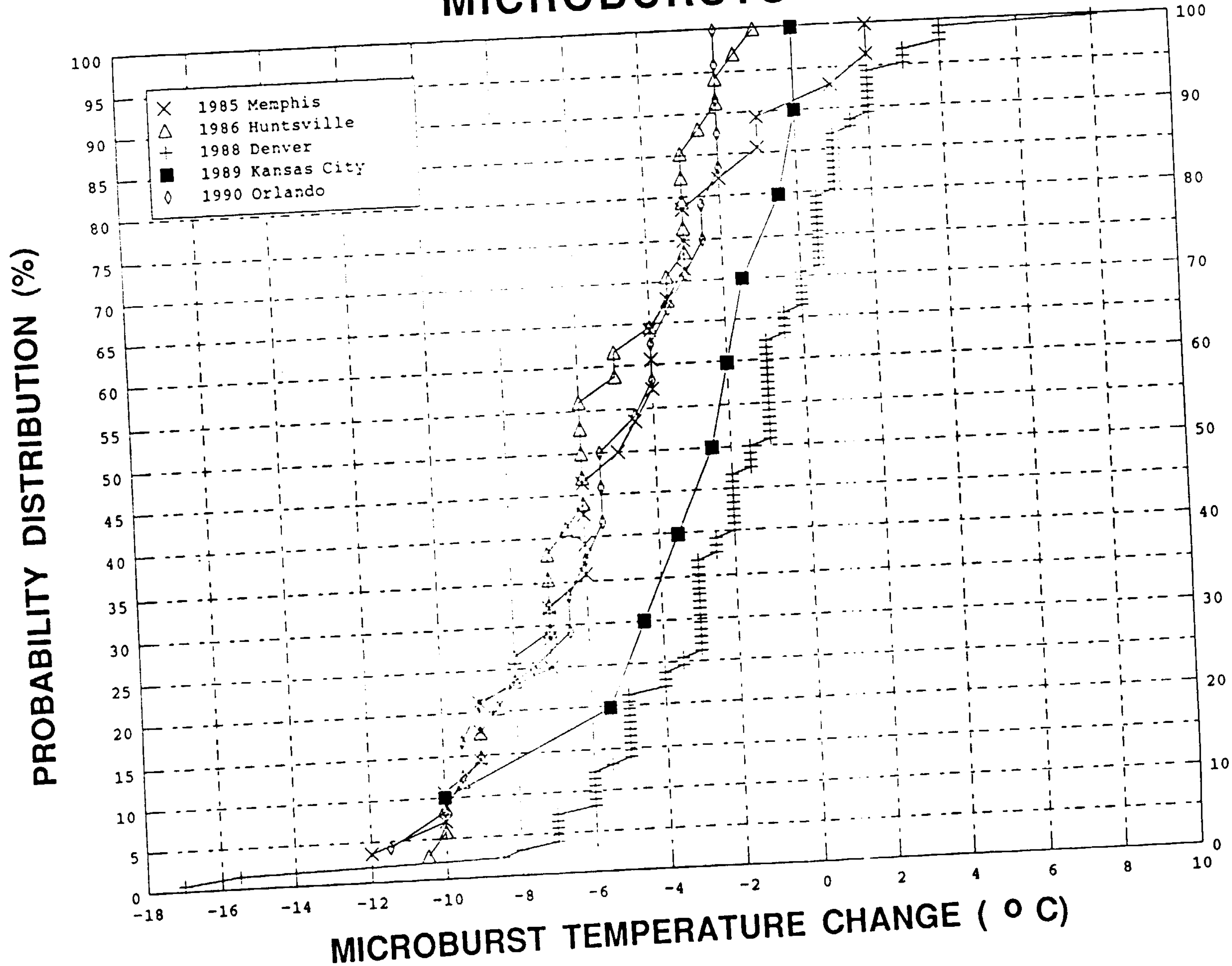


Vugraph #16 "Temperature Changes"

The surface mesonet system used with the TDWR testbed measures temperature every 7 seconds and records the 1 minute average and peak values. The figure shows the temperature changes associated with all microbursts ($\Delta V \geq 10$ m/s) which impacted the mesonet. We see that there is a wide variation in temperatures at the surface with a significant fraction of the events having temperature drops less than 2° C.

It should also be noted (see attached article by Klingle-Wilson, et al) that most gust fronts have temperature changes of -7°.

TEMPERATURE CHANGES ASSOCIATED WITH MICROBURSTS



SUMMARY

- MANY EVENTS HAVE HORIZONTAL DIVERGENCE CORRESPONDING TO $F > 0.1$ AT ALL LOCATIONS
- WIDE RANGE OF REFLECTIVITIES WITHIN INDIVIDUAL MICROBURSTS AND BETWEEN DIFFERENT MICROBURSTS
- EVENTS WITH RHI SCANNING SUGGEST MOST OUTFLOW DEPTHS ARE LESS THAN 300 M AGL AND THAT COVERAGE TO 50-100 M IS HIGHLY DESIRABLE
- SIGNIFICANT FRACTION OF STRONG MICROBURSTS HAVE SMALL SIZES (< 2 KM)
- HIGH RESOLUTION TRIPLE DOPPLER ANALYSES FROM ORLANDO WILL ASSIST IN DEFINING OUTFLOW VELOCITY STRUCTURES

CHARACTERISTICS OF GUST FRONTS *

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1. INTRODUCTION

A gust front is the leading edge of a thunderstorm outflow. A gust frontal passage is typically characterized by a drop in temperature, a rise in relative humidity and pressure, and an increase in wind speed and gustiness.

Gust front detection is of concern for both Terminal Doppler Weather Radar (TDWR) and Next Generation Weather Radar (NEXRAD) systems. In addition, airborne systems using radar, lidar, and infrared sensors to detect hazardous wind shears are being developed (Bowles and Hinton, 1990). The automatic detection of gust fronts is desirable in the airport terminal environment so that warnings of potentially hazardous gust front-related wind shears can be delivered to arriving and departing pilots. Information about estimated time of arrival and accompanying wind shifts can be used by an Air Traffic Control (ATC) supervisor to plan runway changes. Information on expected wind shifts and runway changes is also important for terminal capacity programs such as Terminal Air Traffic Control Automation (TATCA; Spencer, *et al.*, 1989) and wake vortex advisory systems.

In addition, the convergence associated with gust fronts is often a factor in thunderstorm initiation and intensification. Knowledge of gust front locations, strengths, and movement can aid forecasters with thunderstorm predictions.

Current gust front detection systems generally are reliable in that the probability of false alarms is low. However the probability of detecting gust fronts with these systems is less than desired (Evans, 1990). Improved characterization of gust fronts is a key element in improving detection capability.

Typically, the basic products from the algorithms are the location of the gust front (for hazard assessment) and its propagation characteristics (for forecasting). This paper discusses the thermodynamic and radar characteristics of gust fronts from three climatic regimes, highlighting regional differences and similarities of gust fronts. It also compares propagation speeds, estimated by two techniques, to measured propagation speeds.

*The work described here was sponsored by the Federal Aviation Administration. The United States Government assumes no liability for its content or use thereof.

2. DATA AND METHODOLOGY

Measurements made as a part of the Federal Aviation Administration (FAA) TDWR operational demonstrations held in Denver, CO (1988); Kansas City, MO (1989); and Orlando, FL (1990) are used to characterize gust fronts. To support the operational demonstrations, a 30- to 40-station mesoscale network (mesonet) of automatic weather stations, with an average inter-station spacing of 1.4 - 2.1 km, was sited at each airport to measure surface winds, temperature, relative humidity, pressure, and rainfall amounts every minute (Wolfson, 1989). Only gust fronts that passed through the mesonet were considered in this study.

The requirement that a gust front pass over the mesonet limited the number of gust fronts available for analysis. Ten Denver, nine Kansas City and 13 Orlando gust fronts were chosen. Mesonet data were used to determine the surface thermodynamic and kinematic characteristics of gust fronts, while reflectivity thin line characteristics were derived from the TDWR testbed radar (FL-2). Wolfson, et al. (1990) present statistics on gust front strength, length, duration, propagation, depth, and temperature difference between the ambient and outflow air. This paper extends that analysis by characterizing the thermodynamic structure and radar reflectivity thin line signatures of gust fronts from the different climatic regimes.

Gust front temperature and relative humidity were taken from the mesonet data. Figure 1 shows a time series

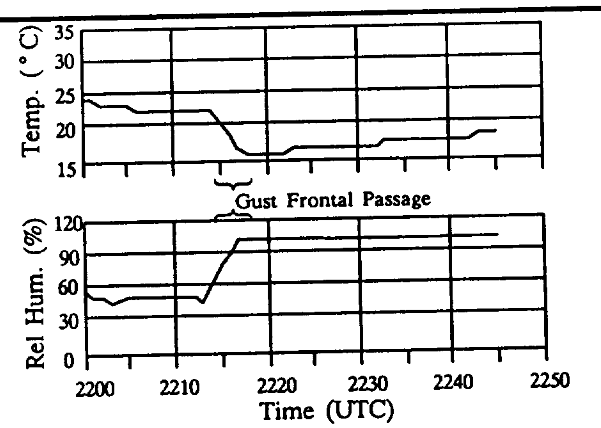

Figure 1. Time series of typical temperature (°C) and relative humidity associated with a gust frontal passage.

plot of the typical temperature and relative humidity associated with a gust frontal passage over a mesonet station. The sharp decrease in temperature and rise in relative humidity at 2215 UTC mark the passage of the gust front. For this gust front, the ambient temperature was 23°C, the outflow temperature was 18°C, and the temperature difference was 5°C. The ambient relative humidity was 50%, the outflow relative humidity was 100%, and the relative humidity difference was 50%. These data were tabulated for each station that experienced the passage of a gust front. The data were then averaged to derive characteristic temperatures and humidities for each gust front.

Gust front propagation speeds and reflectivity thin line characteristics were derived from single-Doppler radar data. The average and peak reflectivities, as well as the average reflectivity ahead of and behind the thin line, were extracted from each gust front event that exhibited a thin line. An event is a single observation of a gust front on a radar volume scan as determined by subjective analysis. Thus, a single gust front scanned five times by the radar would result in five gust front events.

3. GUST FRONT CHARACTERISTICS

Figure 2 provides the distribution of some temperature and relative humidity characteristics of Denver, Kansas City, and Orlando gust fronts. Negative temperature differences indicate that the outflow air was cooler than the ambient air. Averages computed from these data are presented in Table 1. For one Kansas City gust front the outflow was silghtly warmer and less moist than the ambient air.

Table 1. Averages of maximum outflow temperature ($max\overline{T_{gf}}$), minimum outflow temperature ($min\overline{T_{gf}}$), outflow temperature ($\overline{T_{gf}}$), ambient temperature ($\overline{T_{amb}}$), ambient-outflow temperature difference ($\overline{\Delta T}$), maximum outflow relative humidity ($max\overline{RH_{gf}}$), minimum outflow relative humidity ($min\overline{RH_{gf}}$), outflow relative humidity ($\overline{RH_{gf}}$), ambient relative humidity ($\overline{RH_{amb}}$), and outflow-ambient relative humidity difference ($\overline{\Delta RH}$). Temperatures are in °C and relative humidities are in percent.

	Denver	Kansas City	Orlando	All
$max\overline{T_{gf}}$ (°C)	30	27	29	30
$min\overline{T_{gf}}$ (°C)	18	14	20	14
$\overline{T_{gf}}$ (°C)	24	21	25	23
$\overline{T_{amb}}$ (°C)	29	25	32	29
$\overline{\Delta T}$ (°C)	-5	-4	-7	-6
$max\overline{RH_{gf}}$ (%)	82	100	100	100
$min\overline{RH_{gf}}$ (%)	23	53	65	23
$\overline{RH_{gf}}$ (%)	50	86	84	74
$\overline{RH_{amb}}$ (%)	30	74	58	54
$\overline{\Delta RH}$ (%)	20	12	26	20

Kansas City outflows exhibit the greatest range in outflow temperatures (13°C), followed by Denver and then Orlando. Kansas City average ambient and average outflow temperatures are colder than Denver and Orlando temperatures, but the average temperature difference between the outflow and ambient air is smallest in Kansas City.

The relative humidity data show that outflows are driest in Denver. On average, the largest **difference** in ambient-outflow relative humidity is associated with Orlando, followed by Denver and Kansas City.

Outflows from thunderstorms have been shown to be dynamically similar to density currents (Charba, 1974). A density (gravity) current is generated whenever a fluid of greater density moves through a fluid of lesser density. The motive force of the gravity current is the hydrostatic pressure difference between the two fluids. Equation 1 expresses gust front propagation speed in terms of the depth of the outflow head and the difference in virtual temperature between the warm and cold air (Seitter, 1983). This equation

$$V = k'\left[gH\frac{\Delta T_v}{T_v}\right]^{1/2} \qquad \text{(Eqn. 1)}$$

where:

V	=	gust front propagation speed
k'	=	redefined Froude number (~1)
g	=	acceleration of gravity
H	=	depth of gust front head
ΔT_v	=	difference in virtual temperature between warm and cold air
T_v	=	virtual temperature of the warm air.

was used to estimate the propagation speed of the Denver, Kansas City, and Orlando gust fronts for comparison to measured propagation speeds, as deduced from radar data. Head depth was estimated from radar data and virtual temperature was estimated from temperature and relative humidity. The comparison of propagation speeds computed from Seitter's technique and measured propagation speeds is given in Figure 3. In two Denver and three Kansas City cases, the gust fronts did not propagate away from the leading edge of the parent storm and outflow depth could not be estimated. These gust fronts are not represented in Figure 3.

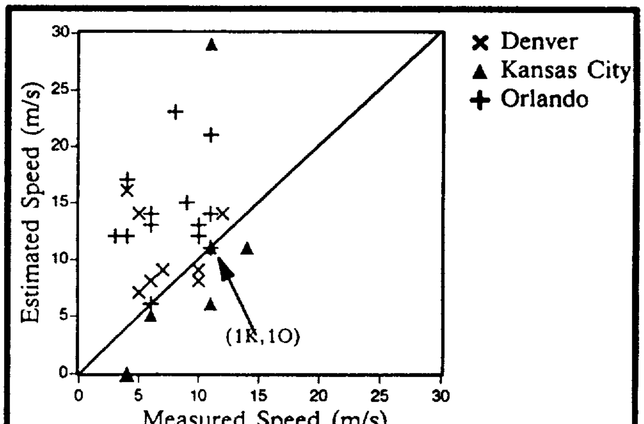

Figure 3. Estimated versus measured gust front propagation speed. Estimated values were computed from Seitter's technique. In cases where data points overlap, the numbers of points for each location (D: Denver, K: Kansas City, O: Orlando) are shown in parentheses.

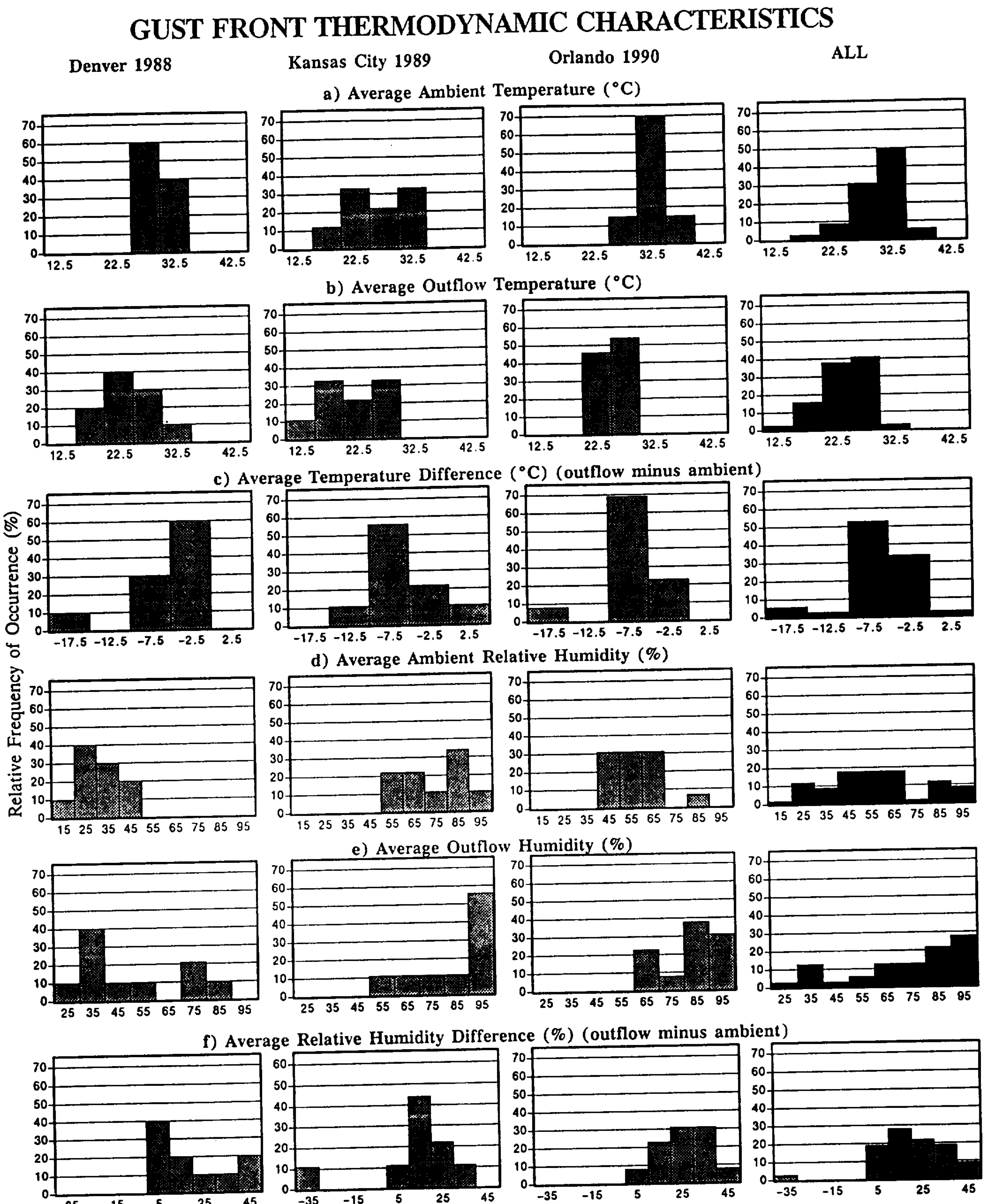

Figure 2. Relative frequency (%) of the average (a) ambient temperature (°C); (b) outflow temperature (°C); (c) temperature difference (°C) between the outflow and ambient air; (d) ambient relative humidity (%); (e) outflow relative humidity (%); and (f) relative humidity difference (%) between the outflow and ambient air. The values on the abscissa are the midpoints of the interval.

Goff (1976) found that propagation speed was roughly 67% of the maximum wind speed in the outflow. This estimate of propagation speed is compared to the measured speeds in Figure 4.

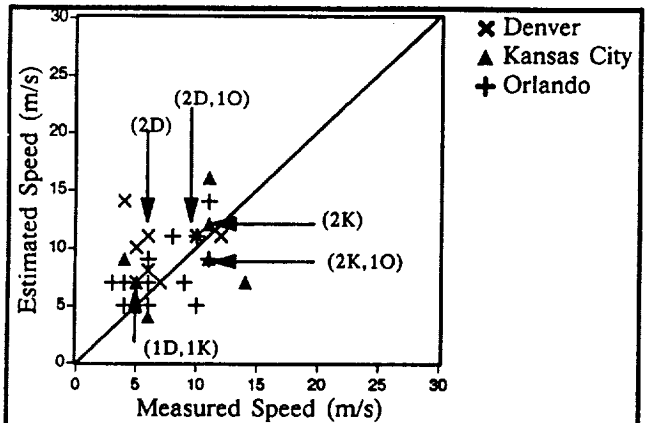

Figure 4. Estimated versus measured propagation speed. Estimated values were derived from Goff's technique. In cases where data points overlap, the numbers of points for each location (D: Denver, K: Kansas City, O: Orlando) are shown in parentheses.

Propagation speed is generally overestimated using Seitter's technique, although the estimated speeds for Kansas City gust fronts were less than the measured values. Goff's technique also tends to overestimate propagation speed, but to a lesser degree than Seitter's technique. The average differences and average absolute differences between the measured and estimated speeds are given in Table 2. The two techniques provide about the same performance for Denver gust fronts, but Goff's estimate is better for Kansas City, Orlando, and over all.

Table 2. Average and average absolute differences between estimated and measured propagation speed for Denver, Kansas City, Orlando, and All locations.

Location	Average Difference	Average Absolute Difference
Seitter's Technique		
Denver	3.3	4.0
Kansas City	0.8	5.2
Orlando	6.3	6.3
All	4.2	5.4
Goff's Technique		
Denver	3.0	3.2
Kansas City	0.1	3.0
Orlando	0.8	2.4
All	1.3	2.8

Figure 5 shows gust front duration, propagation speed and outflow depth as functions of the ambient-outflow temperature and relative humidity differences for gust fronts at the three sites. Since the gust front motive force is the hydrostatic pressure difference between the outflow and ambient air, one would expect those outflows exhibiting the largest temperature differences to move fastest and last longest. The data do not support this expectation, possibly because the velocity of the opposing ambient flow is not considered. In addition, gust front strength is determined from Doppler velocities. Since the radar senses only the along-the-beam component of the flow, strength estimates may be incorrect.

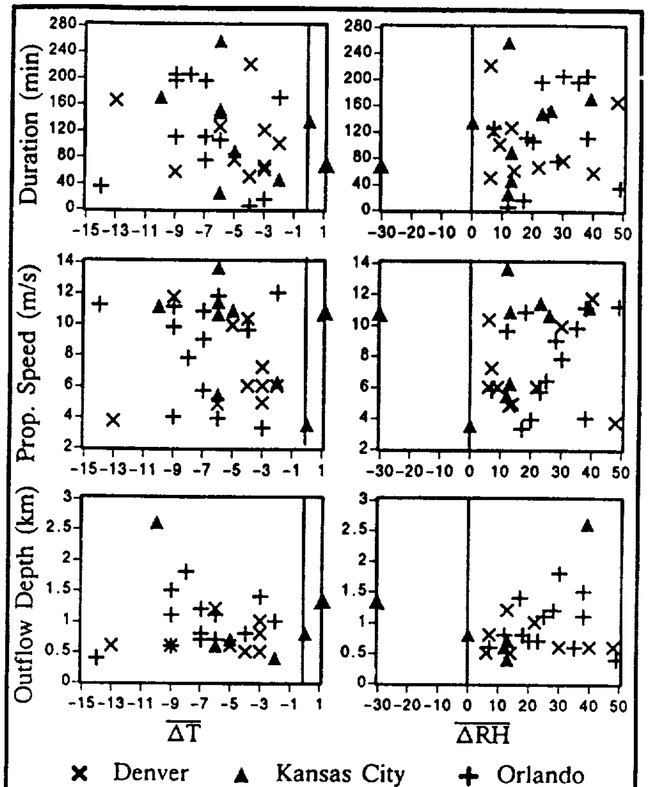

Figure 5. Gust front duration, propagation speed, and outflow depth as functions of the average ambient–outflow temperature difference ($\overline{\Delta T}$) and relative humidity difference ($\overline{\Delta RH}$).

Reflectivity data from gust front events is provided in Figure 6. For detection algorithms, it is important to know not only the reflectivity characteristics of the thin line, but also the reflectivity characteristics of the air on either side of the thin line. For this reason, reflectivities ahead of and behind the gust front are given. Mean values for the measured variables are shown in the upper right corner of each plot. There appears to be no strong regional influence on the peak and average reflectivities in the thin line or in the average reflectivity behind the thin line (*i.e.*, in the cold air). However, the reflectivities of the air ahead of the thin line (*i.e.*, in the warm air) are lower in Denver (-7 dBZ) than in Kansas City (-4 dBZ) and Orlando (-3 dBZ), although these differences are small. If the thin line is visualized as a "wrinkle in a rug" then the wrinkle is higher, and therefore possibly easier to detect, in Denver.

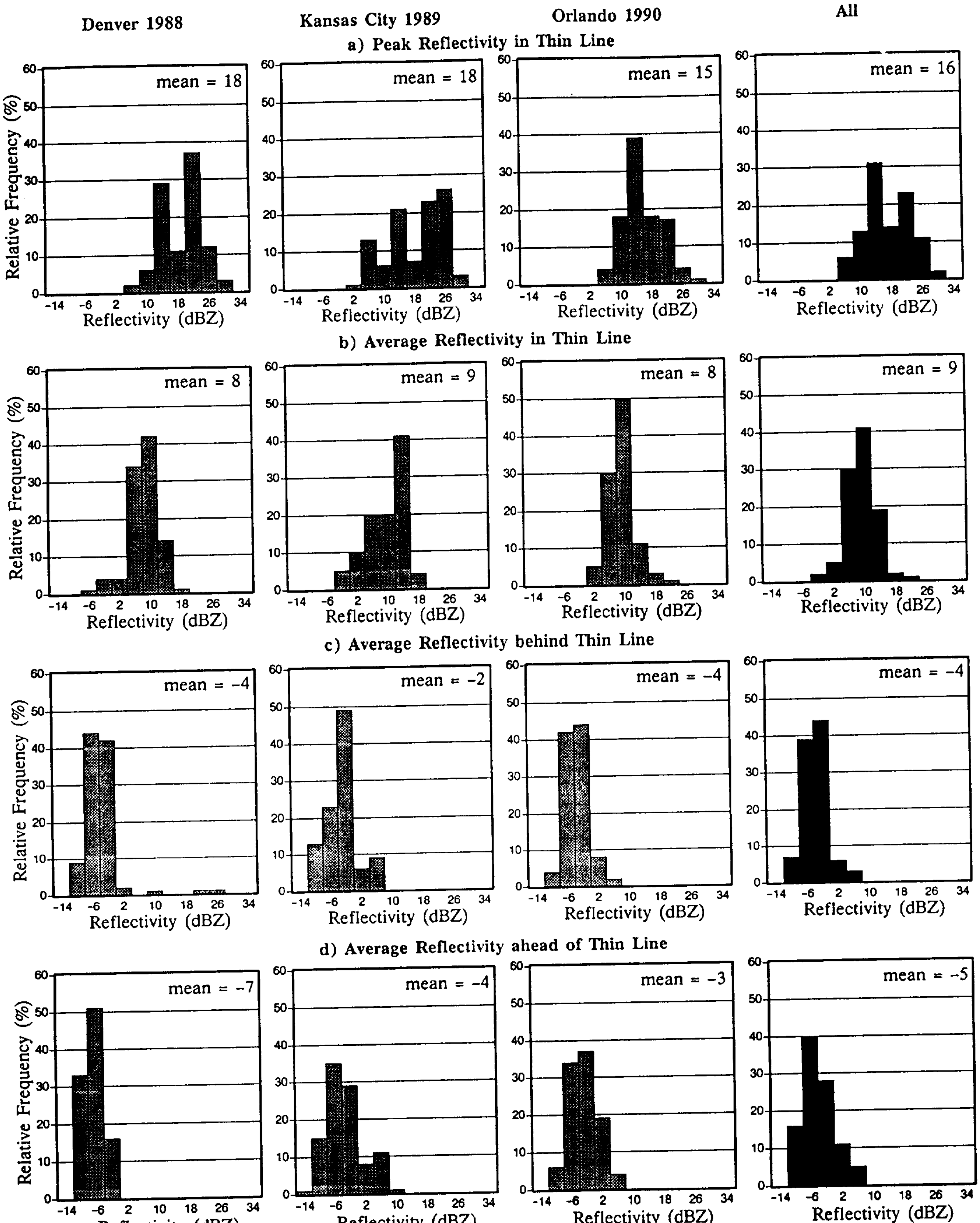

Figure 6. Reflectivity characteristics of gust fronts represented by relative frequency of events at three airports (Denver, Kansas City, and Orlando) for the measured variable. The rightmost graph in each row shows the relative frequency of the measured characteristic for all gust fronts (ALL).

4. SUMMARY

The key to detecting gust fronts is the accurate characterization of the phenomena. Some algorithms rely heavily on radar signatures of gust fronts, while others are based upon sensors that measure temperature changes across the gust front. Regardless of the sensor used to detect gust fronts, it is important to understand the differences and similarities in gust fronts over a variety of climatic regimes.

This paper has shown for the cases studied here that Kansas City outflows are colder than Denver and Orlando outflows; and that Denver outflows are driest. However, the ambient-outflow temperature and relative humidity differences are greatest in Orlando.

Two techniques were used to estimate gust front propagation speed. Seitter's method, which used virtual temperature and outflow head depth, overestimated propagation speed. Goff's method also overestimated propagation speed, but to a lesser degree.

Reflectivity thin lines were also analyzed. The values of reflectivity in the thin lines showed no regional bias. However, the reflectivity of the ambient air was lowest in Denver, which may make Denver thin lines easier to detect.

5. REFERENCES

Bowles, R. L. and D. A. Hinton, 1990: Windshear detection: airborne system perspective, Windshear - One Day Conference, London, England, 1 November 1990.

Biron, P.J., and M.A. Isaminger, 1989: An analysis of microburst characteristics related to automatic detection from Huntsville, AL and Denver, CO. Preprints, *24th Conference on Radar Meteorology*, Tallahassee, Amer. Meteor. Soc., 269-273.

Charba, J., 1974: Application of g-current model applied to analysis of squall-line gust front, Mon . Wea. Rev., 102; pp. 140-156.

Evans, J. and D. Turnbull, 1990: Development of an automated windshear detection system using Doppler weather radar. *IEEE Proceedings*, 77, 1661-1673.

Evans, J.(ed.), 1990: Results of the Kansas City 1989 Terminal Doppler Weather Radar (TDWR) Operational Evaluation Testing, DOT/FAA/NR-90/1 (ATC-171), 78 pp.

Goff, R. C., 1974: Vertical Structure of Thunderstorm Outflows, Mon. Wea. Rev., 104; pp. 1429-1440.

Merritt, M.W., D.L. Klingle-Wilson, and S.D. Campbell, 1989: Wind shear detection with pencil beam radars. *The Lincoln Laboratory Journal*, 2, 483-510.

Seitter, K. L., 1983: Numerical simulation of thunderstorm gust fronts, Air Force Geophysics Laboratory Rept. No. AFGL-TR-83-0329, Envir. Res. Paper No. 862, 34 pp.

Spencer, D. A., J. W. Andrews and J. D. Welch, 1989; An Experimental Examination of the Benefits of Improved Terminal Air Traffic Control Planning and Scheduling, *The Lincoln Laboratory Journal*, V. 2, No.3, Fall 1989, pp. 527-536.

Wolfson, M., D. Klingle-Wilson, M. Donovan, J. Cullen, D. Neilley, M. Liepins, R. Hallowell, J. DiStefano, D. Clark, M. Isaminger, P. Biron, B. Forman, 1990: Characteristics of thunderstorm-generated low altitude wind shear: A survey based on nationwide terminal doppler weather radar testbed measurements, Proceedings of the 29th Conf. on Decision and Control, Honolulu, HI, pp. 682-688.

Wolfson, M.M., 1989: The FLOWS automatic weather station network. *J. Atmos. Oceanic Technol.*, 6, 307-326.

Microburst Characteristics Determined from 1988-91 TDWR Testbed Measurements
Questions and Answers

Q: Roland Bowles (NASA Langley) - In the discussion of your vertical structure charts, for those two events, where was the event relative to the radar?

A: Jim Evans (MIT) - The top event is at a range of seven kilometers. This is scanned vertically and you can see the little x's on all the data points that are actually measured as individual measurements. In the blue event the radar range is 2.7 kilometers, and this is a half degree beam. What we have told them to do is when they see a microburst within about 7 or 8 kilometers to go into an alternative scan pattern and mix in RHI with PPI so that we get very high resolution on the outflows. We have been concerned ourselves about what altitude should we be setting our beams for the TDWR. So we have been trying to understand this whole issue of what the structures are. You have to do it at close range and the fact that we have a half degree elevation beam helps a lot. When we do RHI scanning we measured a whole bunch of angles, so they are pretty closely spaced, particularly at the bottom.

Q: Roland Bowles (NASA Langley) - There is a least one publication that came out of Lincoln that was excellent, were you published a great deal of your findings on half velocity point distribution; the altitudes at which the velocity was half peak. Do you have plans to publish, for those data that you can resolve the peak outflow, those distributions?

A: Jim Evans (MIT) - I think we probably need to put out a yearly report that takes all the ones from the preceding year and just reports them so that people in the community can use it. There is a very thick report that has data all the way up through about 1989 and maybe a little bit of 1990, and contains everything we knew about outflow structure in the vertical domain. We will continue to put out that report and we will continue to try to scan these things as best we can.

Roland Bowles (NASA Langley) - That would be valuable for people working with airborne systems.

Jim Evans (MIT) - It is an absolutely key parameter both for ground based and airborne systems.

Q: Mike Lewis (NASA Langley) - It looks like you have a lot of good data there. When talking about the summary of F-factor values, over what distance are those values taken or are they in fact variable distances?

A: Jim Evans (MIT) - The radar range is keeping track of all the microburst at least all the way out to 30 kilometers. The point I made was that if you start saying that the probability of the microburst occurring is proportional to area you find out that you tend to be weighted to long distances as opposed to short distances.

Q: Mike Lewis (NASA Langley) - Not range from the radar, but over what length were those F-factors values calculated?

A: Jim Evans (MIT) - It is simply taking the difference of the maximum and minimum velocities over whatever distance that occurred. So it is variable. That is an average shear over the outflow region. You may have localized hot spots, which Steve Campbell will talk about. That is one of the caveats and I want to emphasize that this is really a lower bound on what the F's would be if you looked over say one kilometer.

Mike Lewis (NASA Langley) - Essentially, any time you talk about F you need talk about both magnitude and length.

Jim Evans (MIT) - Yes, I understand. The advantage of this particular data is that it is a very large data base. You could take some selective events and go back and reprocess and probably work out a correction.

Q: Mike Lewis (NASA Langley) - You made some points about the core reflectivity versus the outflow reflectivity. Perhaps the message is not quite so bad for radar manufacturers trying to measure that low reflectivity area, because, while the maximum velocities would perhaps be in that outflow area the maximum shears are still in the core. That is the kind of region that we are trying to measure and trying to protect from, and that perhaps is the region of somewhat higher reflectivity.

A: Jim Evans (MIT) - Well, I think Steve will be showing some examples of where the highest shears are in his paper, which I believe is tomorrow. You can decide for yourself whether or not they are in the core.

Steve Cambell (MIT Lincoln Laboratory) - In general, is not necessarily true that the strongest shear is were the strongest reflectivity is. When Jim said cores, he meant reflectivity cores and that is not necessarily where the highest shear is.

Mike Lewis (NASA Langley) - O.K. I thought you were talking about the downdraft core.

Jim Evans (MIT) - The other thing that you have to understand is that in an awful large fraction of the events, particularly in a place like Denver, have multiple outflows bumping into each other. That is why there is asymmetry. Nobody can make an asymmetrical microburst by itself, but they tend to occur in families and that is what is ugly about the whole process.

Mike Lewis (NASA Langley) - My last point is that you mentioned a couple of times about the differences of measuring at a flight test altitude of 1000 feet versus lower altitudes. It seems to me, for the research purpose of determining if your shear detection system is measuring real shear, it is perfectly O.K. to measure at 1000 feet and confirm or deny the measurement with either In Situ measurement, or an estimate from TDWR, at the same altitude. It is not necessarily a flawed flight test to measure at a 1000 feet even if the maximum shear is at 300 feet or so, as long as you confirm your data by other 1000 feet measurements. If the shear from that confirmation equals the shear that your detector is predicting then you are doing a good job.

Jim Evans (MIT) - I guess I disagree. I think we are going beyond that. It isn't the proof that you can measure velocity, I could do it at 3000 feet. The key issue that you the airline buyer and the air passenger ought to ask is; do I have a system that can measure the hazard where the plane has got to fly or infer it properly. That is the key issue. My point is this, if you try to point your antenna down at minus three degrees the clutter challenge goes up dramatically. You may have a system that is viable at measuring shear and velocities at 1000 feet and it is not viable at measuring down at 50 feet. That is the question I think you have to ask the system designer.

Mike Lewis (NASA Langley) - If you are talking about the clutter differences, then I agree completely.

Jim Evans (MIT) - I am talking about the clutter. Low reflectivity microburst have cross sections that are typical of what the military talks about as low observable vehicles. It is not easy to build look down shoot down fighters.

I showed some probability distributions of microbursts as a function of outflow reflectivity and some people asked about the ones that are low reflectivity events with high F values, what would be their distribution? We will try to do that. I thought maybe we could do it for the conference, but I think that is a little to much to promise. We do have it stored in a database. In principal there ought to be no problem in just putting in some more side conditions. That is one of the nice things we have been able to do by having these in a computerized database. Anyone who is interested in finding out about low reflectivity events with high Delta V's or high F-factors and want the characteristics of those, give me your business card and as soon as we get the results run off we will get it to you. We will give it to Roland as well.

Q: Branimir Dulic (Transport Canada) - Why do we think the number of events in Huntsville was underestimated?

A: Jim Evans (MIT) - It was not due to post processing. The number we showed for Huntsville was from the real-time log of microbursts. Subsequently, there was a limited replay operation where we were trying to decide if the radar missed microbursts. We compared the radar to surface wind measurements. We would pick certain days that they had found microbursts by looking at the surface wind measurements and they go back and look at the radar data. What they discovered in doing that was that we did not miss very many events, but the real-time log was missing about half the events that had been picked up in the post processing. It had missed about half of those that had came down over our mesonet, our wind sensors. So on the basis of that, I would presume that we missed about half. What happened was the humans watching the displays in real-time you will see a really strong microburst over here and they might miss another one over some other place that wasn't so distinct. That is the king of thing that a computer does very well and humans get distracted. Because it was a careful but limited after the fact analysis that show we missed about half, I think that is probably true in general.