DUAL-DOPPLER MEASUREMENTS OF MICROBURST OUTFLOW STRENGTH ASYMMETRY

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1. INTRODUCTION

The Federal Aviation Administration (FAA) has been sponsoring Lincoln Laboratory in its effort to develop and test weather detection algorithms for the Terminal Doppler Weather Radar (TDWR). An automated microburst detection algorithm (Merritt et al., 1989) operates on the TDWR radial velocity data and, based on the shear and velocity difference along the radial, outputs regions which are hazards to aviation. This algorithm has been operating since 1987 in Denver, Kansas City, and Orlando and is part of the operational TDWR being deployed across the country. One issue which continues to cause concern for automated windshear detection is microburst asymmetry. Asymmetry, or aspect angle dependence, in microbursts refers to outflows which have a divergent surface outflow strength or extent that varies depending on the viewing angle of the radar.

The TDWR is a single-Doppler radar, therefore, an asymmetric microburst may be underestimated or go undetected if the radar is viewing the event from an aspect angle where the strength of the outflow is weak. Past work by Wilson et al. (1984), Eilts (1987,1988), and Hallowell (1990) has indicated that some microbursts are highly asymmetric. Strength asymmetries (maximum/minimum strength over all viewing angles) from these past studies ranged from 1.3 to as high as 6.0. Hallowell (1990) using Denver data examined 27 Denver microbursts (96 observations) and found strength asymmetries from 1.3 to 3.8 with a median of 1.9. However, this previous work has been limited in scope to Denver and Oklahoma (plains) microbursts, and may have used assumptions about the data which introduce false or apparent asymmetry.

2. APPARENT ASYMMETRY

Previous investigators selected dual-Doppler microburst events using the following criteria:

- Intersection angle of beams between 30° and 150°
- Tilt times of the two radars within one minute
- Elevation angles of both radars less than 1.0°

In the course of studying microburst events, we have found that while these assumptions are valid for large scale, slow moving and developing wind fields, they are not sufficiently strict for microburst outflows. We utilized simulated three-dimensional velocity data of a symmetric microburst obtained using the WME (Wisconsin Model Engine) sub-cloud model (Anderson, 1992). Radial data were extracted from the simulated data from two hypothetical radars situated 15 km from the microburst center at various elevations angles, beam widths, times, and intersection angles. We then input these tilts in various combinations to gather data on how the apparent asymmetry of the event changed for each parameter. Using these model results we were able to quantify the effects of various dual-Doppler coordination parameters on the measured asymmetry of the real microburst data. The following base configuration was used (changes are noted in each sub-section): Fictitious radars located 15 km from microburst center at 90° beam intersection angles, 1.0° beam width, 0.4° elevation angles, and a gate spacing of 150 meters.

2.1. Dual-Doppler Process Itself

The wind synthesis process which operates on the smoothed polar radial velocity data and creates a two-dimensional Cartesian windfield grid introduces asymmetry of its own. By extracting two tilts of fictitious radar data at 90° angles and keeping all other parameters the same, we find a dual-Doppler microburst field which yields an asymmetry of 1.04. This apparent asymmetry has not been removed in the graphs that follow.

2.2. Horizontal Beam Intersection Angles

The angle of intersection between the radar radial data is extremely important in determining the quality of the dual-Doppler wind field. By holding all other parameters constant and changing only the intersection angle of the radars, we see from Figure 1 that intersection angles less than 45° yield increasing apparent asymmetry results.

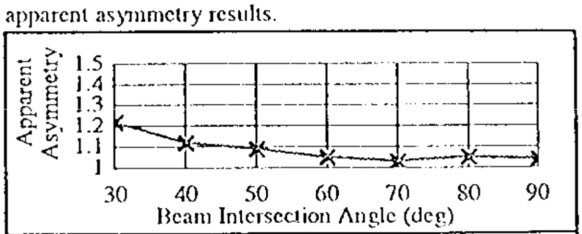

Figure 1. Apparent Asymmetry vs. Intersection Angle

2.3. Temporal Variations

The time between tilts is another key measure of data quality; in microbursts one minute can mean a change in strength of over 10 m/s. Looking at the observations, we find that 90% of the 1 minute changes in differential velocity are less than 7 m/s. The microburst model used has a peak differential velocity of 51 m/s and one minute prior to the peak a velocity of 44 m/s. By matching extracted tilts from different 15 sec time steps (with all other parameters the same), we find that data compared with 45 secs or less time differential yields very low apparent asymmetries (Figure 2). Care should be taken in applying this to all microbursts; rapidly developing or decaying

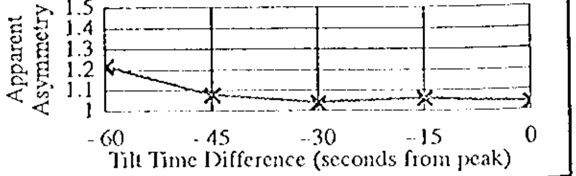

Figure 2. Apparent Asymmetry vs. Time Difference

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microbursts will be more of a problem even in a 30 sec time interval.

2.4. Beam Width, Elevation Angle Differences

On examining these parameters separately it is difficult to discern a pattern. What we finally found was that the extent of vertical beam overlap was the important feature, not a specific beam width or elevation angle. By processing one tilt at 0.0° elevation and its tilt pair at increasingly higher elevation angles we find beam overlap to be the overriding concern for apparent asymmetry (Figure 3). The simulation used for this analysis was for a very strong microburst, and its vertical profile is steeper than that found by Biron and Isaminger (1991) for Denver microbursts. Figure 4 shows the vertical profile of both the simulated data (solid line) and the Denver observations (dashed line). While the overall simulated profile presents a worst case scenario, the lowest 200 m are fairly comparable, and this is where the 30% and greater overlap analysis was performed.

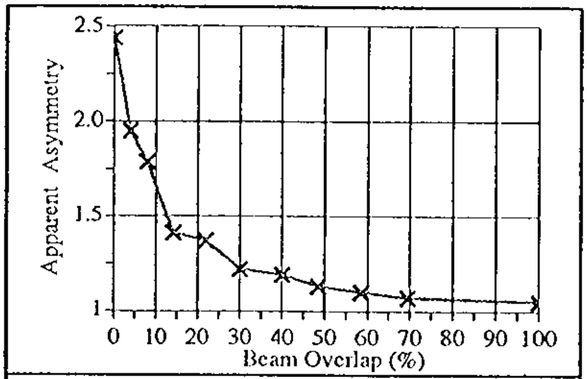

Figure 3. Apparent Asymmetry vs. Beam Overlap

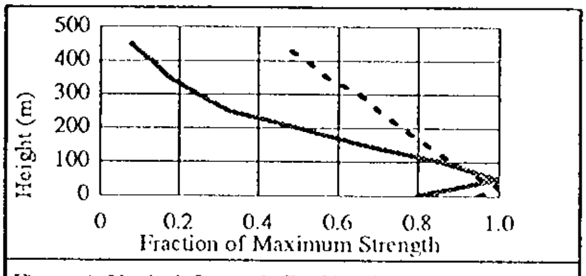

Figure 4. Vertical Strength Profile: Simulated (solid) & Measured (dashed)

2.5. Recommendations

The following criteria were used in this analysis, and should be used by other researchers, to limit the affects of apparent asymmetry on asymmetry analyses:

- Intersection angles between 45° and 135°
- Tilt time differences < 30 secs, and
- Radar beam overlap by 50% or more, or beam centers within 50 m (this guarantees that each radar catches at least a portion of the other radar's center beam).

3. DATA

The data used were collected in Denver, CO (1988), Kansas City, MO (1989) and Orlando, FL (1990). At each site, there were two radars operating: the MIT/LL TDWR testbed radar (FL-2) and the University of North Dakota C-Band Doppler Radar (UND). FL-2 and UND both have one degree beams, FL-2 was an S-Band radar prior to 1990 but modified to C-Band in 1990. The radar scanning was coordinated to cover microbursts which occurred in favorable dual-Doppler regions. For each scan of an event, the two-dimensional surface wind field was calculated using the multiple Doppler radar synthesis system suggested by Brown et al. (1981). The raw two-dimensional wind fields were then smoothed once using a simple 3-by-3 median filter, with 4 of 9 points required to be valid.

Microbursts were selected by examining the two-dimensional windfield for divergence regions. This subjective examination process yielded over 1000 observations and some 100 events (multiple observations of the same microburst). Some observations, taken at the beginning or end of an event, were not true outflows and were removed from the analysis by dropping observations which had minimum differential velocities less than 3.5 m/s. With this restriction, a total of 859 observations of microbursts were examined for asymmetry; a breakdown by site is shown in Table 1.

Table 1.Breakdown by Site of Data Examined

	Days	Events	Observations
Denver	6	36	476
Kansas City	7	27	163
Orlando	4	22	220
Totals	17	85	859

4. METHODOLOGY

The methodology used to analyze microburst events from dual-Doppler is essentially the same as that detailed by Hallowell (1990). Briefly, an analyst examines the wind field and draws a polygon around a microburst outflow. Gridpoints of velocity data within the polygon are then intercompared to calculate velocity differences. Every gridpoint pair has its own orientation angle with respect to North (based on a fictitious radar 15 km from the event, see Figure 5), from which we can determine what the peak differential is at various orientation angles.

5. RESULTS

Three sites and 859 observations of microbursts were examined for this study. When the strict criteria from Section 2.5 are applied, we find a definite shift toward lower asymmetry as shown in Figure 6. The median asymmetry ratio for the re-

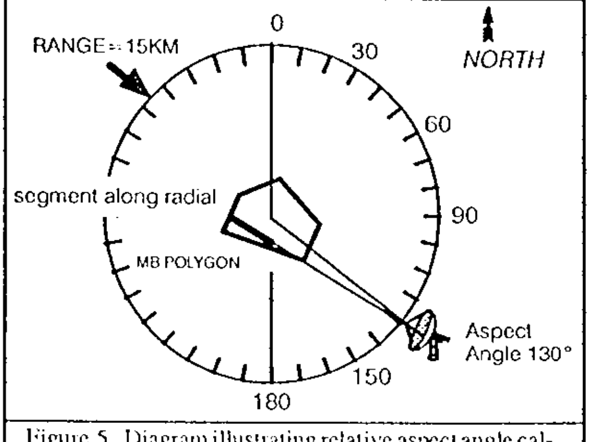

Figure 5. Diagram illustrating relative aspect angle calculations for asymmetry analysis.

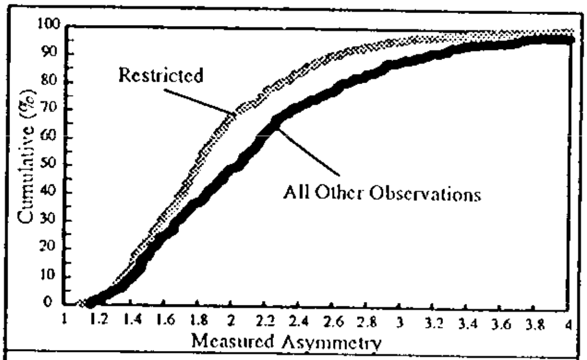

Figure 6. Percent Frequency of Asymmetry Ratios for Restricted (grey) and All Other Observations (black).

stricted set of data (498 observations) is 1.78 while all other observations have a median asymmetry over 2.0 (361 observations). By no means has all the apparent asymmetry been eliminated; restricting cases to remove all apparent asymmetry would leave no observations to work with. However, a reasonable estimate of the lowest possible real asymmetry curve can be made based on the known apparent asymmetry error left in the data. The measured asymmetry can be obtained by applying the following formula:

$$A_{measured} = A_{real} * A_{time\_diff} * A_{beam\_angle} * A_{overlap} * A_{dual}$$

This formula assumes a worst case scenario, where the asymmetries due to temporal variations (A_{time_diff}), beam intersection angles (A_{beam_angle}), elevation angle overlap ($A_{overlap}$), and the dual-Doppler process itself (A_{dual}) compound one another. Sometimes the apparent asymmetries may be oriented such that they actually counteract one another, although the test data studied indicates this is less likely. By restricting the data, I have attempted to limit the impact of each apparent asymmetry to under 5% for A_{dual}, A_{time_diff}, A_{beam_angle}, and to under 15% for $A_{overlap}$. By dividing the restricted measured asymmetry curve by our estimated error ($1.15 * 1.05^3 = 1.33$), I obtain a measure of the expected cumulative distribution of real asymmetry (Figure 7). The chart indicates the real asymmetry median could be as low as 1.34, but the actual answer likely lies between the two curves.

If we examine asymmetry on a site by site basis, we find that for each site the restricted data set yields lower asymmetries than unrestricted data (not shown). Figure 8 shows the cumulative distribution of asymmetry ratios for each of the three sites examined. Orlando and Denver turn out to have very similar distributions of asymmetry, with medians of 1.72 and 1.76, respectively. Kansas City shows a tendency toward higher asymmetry (median 1.9), however 1989 was an atypical climatological year there. Because of this, the quality and quantity of the data collected in Kansas City may have been insufficient to make any firm conclusions about midwest microbursts.

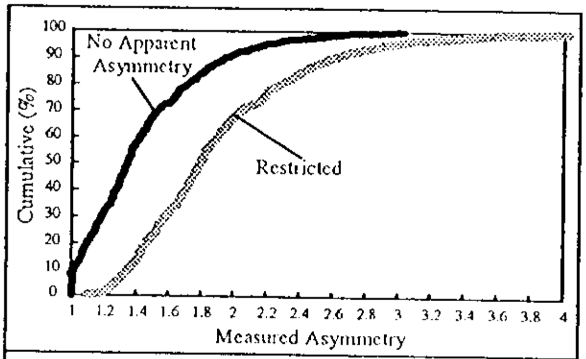

Figure 7. Cumulative Frequency of Ratios for Restricted Data: Measured (grey) and No Apparent Asymmetry (black).

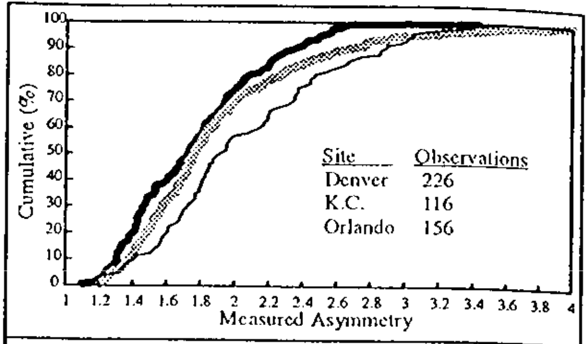

Figure 8. Cumulative Frequency of Ratios for Restricted Data: Denver (grey), Kansas City (thin black), and Orlando (thick black).

6. CONCLUSIONS

Previous studies of microburst asymmetry have not considered the impact of radar configurations, thereby, introducing apparent asymmetry into the analysis. By using simulated data we are able to estimate the impact of temporal difference, vertical beam overlap, and horizontal beam intersection angle factors in processing and analyzing dual-Doppler microburst events. A total of 859 microburst observations were examined from three geographical regions. We find that overall asymmetry distributions are lower than had been found in all previous studies, and that differences in asymmetry between sites such as Orlando and Denver are minimal. Overall, the measured asymmetry ratios in the observation data vary from 1.1 to 4.0 (with less than 5% over 3.0) and have a median value of 1.78. In addition, estimating and removing the residual errors of apparent asymmetry from the observation data set yields a distribution of 1.0 to 3.0 and a median of 1.34.

ACKNOWLEDGEMENT

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