ANALYSIS OF MICROBURST OBSERVABILITY WITH DOPPLER RADAR THROUGH COMPARISON OF RADAR AND SURFACE WIND SENSOR DATA

David A. Clark and John T. DiStefano

M.I.T. Lincoln Laboratory
Lexington, MA 02173

1. INTRODUCTION

As part of the FAA Terminal Doppler Weather Radar (TDWR) measurement program in Huntsville, AL and Denver, CO during 1986 and 1987, respectively, the ability of a single Doppler weather radar to observe microburst outflow signatures (i.e. show identifiable radial velocity patterns) was assessed by comparing radar-observed microbursts with those identified by joint use of both radar data and data from a mesoscale network (mesonet) of surface meteorological stations (Clark, 1988; DiStefano, 1988). Observability by radar must be considered together with pattern recognition algorithm performance for observable microbursts (Campbell et al.,1989) in order to fully assess the potential effectiveness of an automated microburst detection system which relies on data from a single Doppler radar. The comparison of radar and surface sensor data presented here investigates the possibility that some outflows may not be observable by radar due to:

(1) low SNR (signal-to-noise ratio),
(2) very shallow outflows for which the radar beam is scanning too high above the surface,
(3) blockage of the beam, and/or
(4) asymmetry in the surface outflow causing the radar to significantly underestimate the magnitude of the surface wind shear (Eilts and Doviak,1987; GAO, 1987).

Also addressed is the possibility that microbursts are not observed by the mesonet surface sensors because the spacing between stations is too great, or because the microburst outflow does not reach the surface due to a dense layer of cold air at the surface.

The radars used in collecting data were an S-band radar (FL-2) developed and operated by Lincoln Laboratory for the FAA (Evans and Turnbull, 1985), and a C-band radar that was operated by the University of North Dakota (UND). The mesonet system, from which surface meteorological data were collected, consisted of:

(1) PROBE (Portable Remote OBservations of the Environment) weather stations (Wolfson et al., 1986),
(2) a Low-Level Windshear Alert System (LLWAS), and
(3) NCAR's second generation Portable Automated Mesonet (PAM II) network (Pike et al, 1983), used during 1986 only.

Table 1 contrasts the characteristics of the mesonet during the 1986 and 1987 data collection periods. The configurations of both networks are shown in Figures 1 and 2. Both the PROBE and PAM II networks collected data on several meteorological parameters (barometric pressure, relative humidity, temperature, precipitation rates, average and peak wind speed and direction) while the LLWAS sensors recorded only wind speed and direction.

Surface mesonet observations of microbursts were compared with the corresponding radar fields by experienced meteorologists to determine whether a given microburst outflow was observable by the radar. The first section of this paper describes the methodology used for this comparison study, while the second section summarizes the results. The last section details certain aspects from specific cases in which the radar failed to observe the microburst outflow.

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2. METHODOLOGY

2.1 Using Doppler Radar Data

The FL-2 radar, which provides a 0 dB SNR for -15 dBz at a range of 15 km, was used as the primary source of radar data for identifying microbursts. However, UND radar data were used when FL-2 data were not available, or if an event identified by the surface mesonet went unobserved by FL-2. It should be noted that the scanning sequence used in 1986 occasionally resulted in an update interval for surface scans of 4 to 5 minutes, instead of the desired one minute update rate. As a result, the observability of a small percentage of events was deemed inconclusive, and these events were categorized with those for which no radar data were available. Scanning strategies during 1987 in Denver provided a faster update rate of approximately once per minute for surface scans, thus minimizing this problem.

In order for an event to be classified as a microburst, it had to have exhibited a minimum velocity differential of 10 m/s within a horizontal range of no more than 4 km along a radial extending across the outflow area. Merritt (1987) used a similar microburst definition, but he also imposed spatial and temporal requirements on the divergent outflow signature. The current TDWR microburst detection algorithm (Campbell and Merritt, 1987) uses a similar definition of a microburst as observed in the surface velocity field (with a slightly lower threshold), but requires that a surface outflow whose radial mean velocity difference is less than 10 m/s (but $\geq$ 7.5 m/s) be associated with meteorological phenomena aloft. Also, microburst truthers, those experienced radar meteorologists who determine the existence of microbursts from radar data to assist the algorithm developers with their evaluation, have been less stringent as measurements are allowable across a velocity couplet whose orientation is offset from the radial direction.

Table 1. Characteristics of the 1986 and 1987 mesonets.

	1986			1987
	HUNTSVILLE			DENVER
	APR-MAY	JUN-JUL	AUG-SEP	JUN-JUL
PROBE Stations	30	30	30	30
PAM II Stations	--	41	--	--
LLWAS Stations	6	6	6	12
Coverage Area (km^2)	500	1000	500	150†
Avg station spacing (km)	3-5	1-4* 4-8**	3-5	2-2.5†
Max radar range (km)	22	31	22	22

* Within 20 km to the north and west of the FL-2 radar
** Greater than 20 km to the north and west of FL-2 radar
† Includes stations 1-28 and all LLWAS stations

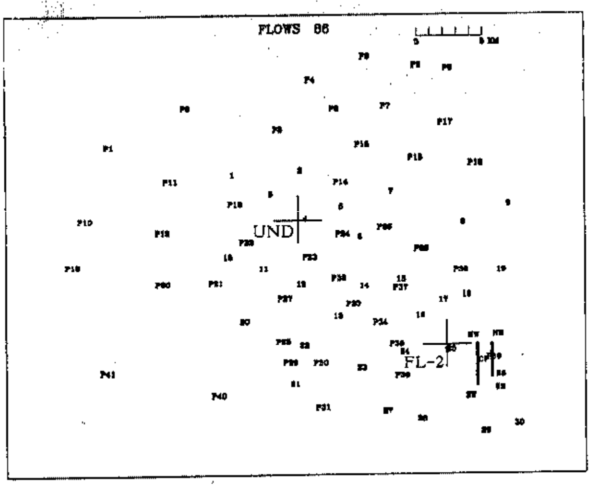

Figure 1. The 1986 TDWR testbed mesonet in Huntsville, AL. 2 radars denoted by cross marks, PROBE stations labeled 1 through 30, PAM stations labeled P1 through P41, and 6 LLWAS stations labeled by ordinal direction. Runways of the Huntsville Airport are denoted by straight lines in southeast corner of the network.

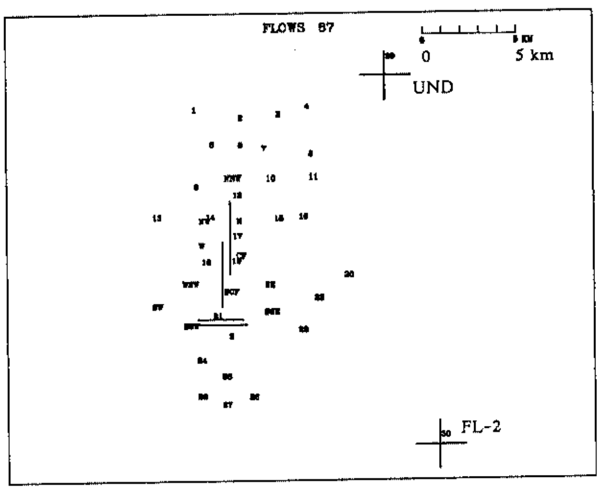

Figure 2. The 1987 TDWR testbed mesonet in Denver, CO. 2 radars denoted by cross marks, PROBE stations labeled 1 through 30, and 12 LLWAS stations labeled by ordinal direction. Runways of Denver's Stapleton International Airport are denoted by straight lines near the center of the network.

Although the microburst signature is ultimately identified in the Doppler velocity field, more supportive information can be obtained from the reflectivity field. For a wind shear event to be classified a microburst, a parent cloud is required from which the event can emanate (Fujita, 1985). Identification of this parent cloud was straightforward for Huntsville microbursts, having been easily identified in the low-level reflectivity field. In Denver, however, it was not always obvious from the low-level radar reflectivity field that a cell existed even though a distinct outflow signature in the Doppler velocity field was present. In cases such as this, it was necessary to look aloft in order to clearly identify the cell. Fujita (1985) has made reference to similar types of microbursts which have been observed in the Denver area during the Joint Airport Weather Studies (JAWS) Project of 1982. These events are classified as "dry microbursts" and are commonly seen in dry regions (e.g. Denver) where the convective clouds have deep (several km) sub-cloud layers. Virga is often observed falling from this type of cloud, hence, the low or negligible reflectivity values at the surface. During 1987 in Denver, only one event, which occurred on 6 July, indicated a surface divergent signature where differential velocity values of 10–15 m/s were observed for a short period, but where no parent cloud existed. In this case a wind shear event was evident, but because no parent cloud could be identified the event was not classified as a microburst.

2.2 Using Surface Mesonet Data

Surface mesonet data was processed as described in Wolfson et al., (1986). For each day, a 24-hour time series plot containing values of the various meteorological parameters for each station was produced. These plots were analyzed to identify potential wind shear events. The primary indicator was a sharp peak in wind speed at one or more stations, accompanied by a change in wind direction.

Once potential shear events were identified from the 24-hour plots, a series of one minute synoptic plots depicting the wind field were analyzed for the appearance of surface divergence. As with the radar data, a divergence of at least 10 m/s across a distance of no more than 4 km was necessary in order to classify an event as a microburst. However, due to the spatial undersampling of the surface mesonet field, it was not always possible to calculate the differential velocity of an event within the suggested 4 km distance. This was especially true in Huntsville where the station spacing in some areas of the mesonet was greater than 4 km. When this occurred, calculations were performed to determine whether the area of divergent winds exhibited the necessary horizontal shear of at least $2.5 \times 10^{-3}\ s^{-1}$, corresponding to a 10 m/s differential velocity within 4 km.

The reliability of the methodology described herein as a suitable approach for microburst identification was supported through comparison with a parallel independent study performed under the direction of T. Fujita at the University of Chicago using a subset of the 1986 Huntsville data. Their methodology was based on an objective single-station detection algorithm (Fujita, 1985). Results from the two studies showed consistency in identifying microbursts, with most discrepancies easily explainable by the differing characteristics of the two identification approaches (peak wind threshold–vs.–surface divergence threshold).

3. SUMMARY OF RESULTS

3.1 Overall Results

During the 1986 and 1987 data collection seasons, it was estimated based on Doppler radar and mesonet surface data that 233 microbursts impacted the mesonet area. These microbursts were observed during the periods 3 April – 9 December and 6 June – 5 October during 1986 and 1987, respectively.

Of these 233 known microburst events, 173 (74.3%) occurred for which data were available from both the radar and mesonet surface sensors (Table 2 shows the statistics for each year). Of those 173 events:

(1) 152 (87.9%) were observed by both the radar and mesonet,

(2) 15 (8.7%) were unobserved by the mesonet surface sensors, and

(3) 6 (3.4%) were unobserved by the radar, corresponding to a radar observation percentage of 96.6%.

Table 3 categorizes these 173 microbursts according to their observed strength. 34% of these events were identified by maximum velocity differences of at least 20 m/s. The radar observation percentage for these stronger microbursts was 98% (56 of 57). As for the events that went unobserved, spacing of the mesonet stations was the cause for the mesonet misses (i.e. the station density was too sparse), while a few reasons accounted for the radar misses. During 1987, low SNR was the cause for all four radar misses, as each was a low reflectivity or "dry" microburst. In 1986, asymmetric outflow accounted for one of the misses, while the inability of the FL-2 radar to observe a very shallow outflow accounted for the other; both instances were categorized as very weak microbursts, i.e. maximum differential velocities of less than 15 m/s. Table 4 summarizes the causes for the radar and mesonet's failure to observe these microburst events.

Table 2. Mesonet impacting microburst statistics for 1986 and 1987

	Mesonet Impacting MB'S	Radar/Meso Data Available	Observed By Both Radar/Meso	Unobserved By Mesonet	Unobserved By Radar
1987	102	66	61	1	4
1986	131	107	91	14	2
TOTAL	233	173	152	15	6

Table 3. Categorical distribution according to the strength of the mesonet-impacting microbursts that occurred during 1987 in Denver and 1986 in Huntsville for which both radar and mesonet data were available.

	Maximum Differential Velocity (m/s)			
	<15	15≤dV<20	≥20	
1987	18	17	31	Number of Microbursts
1986	49	32	26	
TOTAL	67	49	57	

Table 4. Causes for the 1986 and 1987 mesonet-impacting microbursts being unobserved.

UNOBSERVED EVENTS BY:	CAUSES	
	1986	1987
RADAR	Asymmetry Shallow Outflow	Low SNR
MESONET	Spacing	Spacing

3.2 Microbursts Unobservable by Radar

During the 1986-1987 data collection periods, there were six microbursts identified by the mesonet which did not exhibit an observable Doppler velocity signature. This section provides a brief description of the circumstances regarding these events.

3.2.1 Asymmetric Outflow Case

The first microburst in this study that was unobservable by radar occurred on 1 June 1986. It exhibited divergent winds within the surface mesonet from 2201-2216 UT, but maintained microburst-strength shear for only a brief 2-minute span with a maximum differential velocity of 12 m/s measured at 2203 UT (Figure 3). Although the divergent outflow was apparent in the FL-2 radial velocity field, the microburst-strength threshold was not attained; a maximum differential velocity of 7 m/s was measured at 2201 UT. Unfortunatley, no UND radar data were available for comparison. The unobservability by FL-2 was attributed to asymmetry in the surface outflow, with an orientation unfavorable to the viewing angle of the radar.

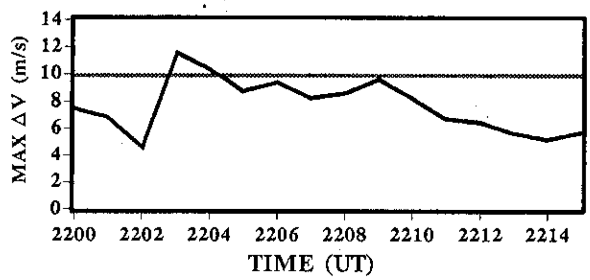

Figure 3. Maximum differential velocity values computed over mesonet using actual measured winds for times specified on 1 June 1986. Horizontal line indicates microburst threshold.

This asymmetry was investigated by measuring the differential velocity along several axes running through the center of the microburst outflow region, with one of the axes oriented along a radial from FL-2. Values of wind direction and speed along the axes were interpolated from the actual winds of surrounding surface sensors. The maximum differential velocity was measured at 2203 UT along an axis oriented approximately north-south. Situated 12 km to the southeast of the microburst, FL-2 was observing the event from just about the least favorable viewing aspect possible. To check the integrity of the FL-2 measurements, the mesonet wind field was plotted using only the radial wind components of each station with respect to FL-2 (Figure 4). The figure

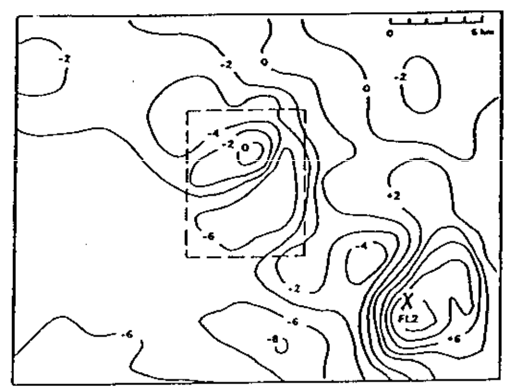

Figure 4. Radial component with respect to FL-2 radar of mesonet-measured wind field for 2203 UT on 1 June 1986, in m/s. Location of FL-2 radar marked by X.

confirms the maximum velocity difference observable by FL-2 as a 7-8 m/s couplet oriented northwest-southeast, in accord with the actual FL-2 measurement.

3.2.2 Shallow Outflow Case

This microburst occurred on 13 July 1986 and was unique to this study in that it was unobservable by the FL-2 radar, but observable by the UND radar. The microburst was weak and its outflow was extremely shallow (approximately 100 meters in depth). Closer proximity to the event allowed the UND radar to view the microburst outflow closer to ground level than did FL-2, and this appears to account for the difference in observability.

Viewing the event at 2045 UT from a distance of 4 km to the southeast, UND observed an 11 m/s differential velocity in its lowest elevation scan (0.5 degrees) at a height of approximately 35 m AGL (Figure 5). At 1.5 degrees elevation (approx. 100 m AGL) the differential velocity decreased to 9 m/s, slightly below microburst threshold. At 2.5 degrees, the radial velocity signature became purely rotational, and no horizontal divergence was apparent. At the same time, FL-2 was also viewing the microburst from

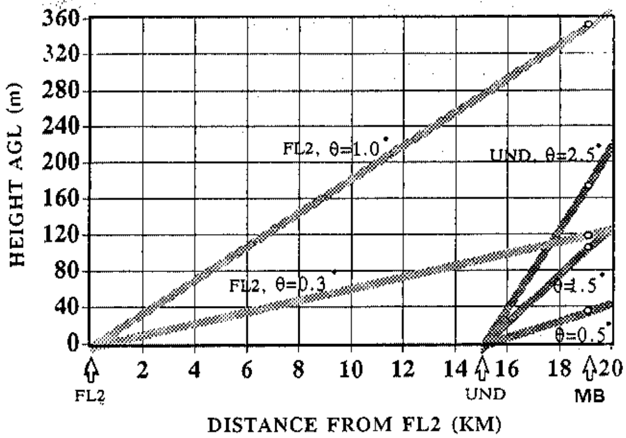

Figure 5. Height of radar beam above ground level for low-elevation scans from FL-2 and UND radars. MB indicates location of microburst.

the southeast, but from a distance of 19 km. Its lowest scan of 0.3 degrees elevation measured a differential velocity of 8 m/s at a height of 120 m AGL, consistent with the measurements of UND, but at a height above the depth of the microburst strength outflow. Similar viewing angles of the two radars discounts a discrepancy due to outflow asymmetry, and the difference in observability is attributed to the shallow depth of the microburst outflow.

3.2.3 Low SNR Cases

There were four mesonet impacting microbursts which went unobserved by radar during 1987 in Denver. All were "dry" microburst events as distinguished by their very low SNR measurements, and only one of these was categorized as a strong event (see Table 5). The Doppler velocity fields associated with these events were extremely noisy, showing no discernible microburst signature. The only exception was from the first missed event on 2 September in which a divergent outflow signature was briefly identified by the FL-2 radar before being completely obscured by noise.

Table 5. Classification by strength of microbursts unobserved by radar during 1987 in Denver, CO due to low SNR. Weak ($10 \leq dV < 15$), Moderate ($15 \leq dV < 20$), Strong ($dV \geq 20$), where dV=differential velocity (m/s).

DATE	TIME (UT)	CLASS
29 AUG	0121-0125	WEAK
2 SEP	2242-2253	STRONG
2 SEP	2253-2304	WEAK
13 SEP	2113-2118	MODERATE

4. SUMMARY

This paper has investigated the observability of microbursts with Doppler weather radar and surface anemometers through a comparison of radar and surface mesonet data from 1986 in Huntsville, AL and 1987 in Denver, CO. There were 173 microbursts identified for which both radar and surface data were available for comparison. 167 of these microbursts were observable by radar, corresponding to a radar observability percentage of 96.6%. When considering only strong microbursts (i.e. velocity differences of at least 20 m/s), the radar observability improved to 98.2%, as 56 of 57 such events were observable.

The microbursts observed in Huntsville were predominantly of the "wet" variety, as expected, and the radar observability was 98.1%. There were two microbursts that were not observable by radar: the unobservability of the first was attributed to an asymmetric outflow with the FL-2 radar viewing from an unfavorable angle, while the other was attributed to an outflow depth limited to a height below that of the lowest radar elevation scan. Both of these microbursts were extremely weak and short-lived, attaining maximum differential velocities below 15 m/s. Insufficient signal return did not pose a problem with radar observability, as no events were missed due to low reflectivity.

The radar observability of microbursts in Denver was 93.9% for all events, and 96.8% for strong events. In contrast to Huntsville, all four missed radar observations were attributed to insufficient signal return.

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