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MICROBURST RECOGNITION PERFORMANCE OF TDWR OPERATIONAL TESTBED

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1. INTRODUCTION

This paper describes current work in assessing the microburst recognition performance of the Terminal Doppler Weather Radar (TDWR) operational testbed. The paper is divided into three main sections: microburst recognition algorithm, performance assessment methodology and results. The first section provides an overview of the prototype TDWR microburst recognition algorithm. The algorithm uses radar data from both surface scans and scans aloft to identify microburst events. The surface scan is used to identify microburst outflows, and the scans aloft provide information concerning reflectivity and velocity structures associated with microbursts to improve recognition rate and timeliness.

The second section of the paper describes the methodology for assessing the recognition performance of the system. The performance of the testbed system is addressed from two viewpoints: radar detectability and pattern recognition capability. The issue of radar detectability is examined by comparing radar and mesonet data to determine if any events observed by the mesonet fail to be observed by the radar. The issue of pattern recognition performance is assessed by comparing microburst recognition algorithm outputs with truth as determined by expert radar meteorologists.

The final section of the paper provides performance results for data collected by the testbed radar at Huntsville, AL and Denver, CO.

2. MICROBURST RECOGNITION ALGORITHM

The prototype TDWR microburst recognition algorithm was implemented in the FAA Lincoln Laboratory FL-2 radar testbed, and successful real-time operation was demonstrated in a two- month operational test during the summer of 1988 at Stapleton airport in Denver, CO. The initial version of the microburst recognition algorithm used surface velocity data only to identify the characteristic surface outflow signature associated with microbursts [Merritt, 1987]. The algorithm was subsequently augmented with the use of features aloft to improve the timeliness and reliability of microburst recognition [Campbell, 1988]. The current version of the TDWR microburst recognition algorithm is described in Campbell and Merritt, 1988.

The prototype TDWR microburst recognition algorithm is divided into three types of modules: feature extraction, vertical integration and microburst recognition. The feature extraction modules identify two-dimensional regions of precipitation and shear from base reflectivity and velocity data. The shear regions identified include divergence, convergence, and rotation; the precipitation regions include three levels of reflectivity processing (e.g., 15, 30 and 45 dBZ). These modules are invoked for each elevation scan.

The vertical integration modules combine the regions identified from scans aloft into three-dimensional reflectivity and velocity structures. Velocity structures include convergence aloft, rotation aloft, divergence aloft (i.e., storm top divergence) and lower divergence (i.e., above the surface but below 1 km AGL). Reflectivity structures include reflectivity cores, storm cells and low reflectivity cells.

The microburst recognition modules use these structures aloft to aid the recognition of microbursts from surface outflows. The surface outflow algorithm identifies microburst outflows using only the temporal and spatial correlation of surface divergence features. The microburst precursor algorithm recognizes structures aloft which indicate that a microburst is imminent, such as a descending reflectivity core coupled with a convergence aloft. The surface microburst algorithm uses structures aloft and precursors to aid the recognition of microbursts from surface outflows. For example, an early microburst declaration can be made from a weak surface outflow combined with a microburst precursor signature. A further discussion of the use of features aloft in the prototype TDWR microburst recognition algorithm is provided in Campbell and Isaminger, 1989.

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3. PERFORMANCE ASSESSMENT METHODOLOGY

The performance of the TDWR microburst detection system is evaluated in two stages. First, the fundamental ability of the radar system to observe the microburst divergent outflow is examined. This part of the evaluation determines the probability that a given microburst will be observed by the radar. Reasons for failing to observe a microburst include: very shallow outflow, asymmetry of outflow winds, beam blockage, low signal strength and clutter obscuration. The second stage of the evaluation determines the probability of detecting the microburst radar signature, using automated pattern recognition algorithms, given that the radar signature has been observed by the sensor. The overall system detection rate may then be obtained as the product of these two subsystem detection rates.

3.1 Radar Observability Assessment

The ability of the radar to observe microburst outflow signatures is obtained by comparing radar-observed microbursts with those identified by a network of surface weather stations. This comparison has been completed for data collected during 1986 at Huntsville, AL, and during 1987 and 1988 at Denver, CO. The radars used 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 operated by the University of North Dakota (UND).

Surface meteorological data were collected using a mesonet system consisting of 30 PROBE (Portable Remote OBservations of the Environment) weather stations [Wolfson et al, 1986], and 6 to 12 Low-Level Windshear Alert System (LLWAS) stations. This network was supplemented for a two-month period in 1986 by 41 additional Portable Automated Mesonet (PAM II) stations supplied by the National Center for Atmospheric Research. Table 1 summarizes the characteristics of the mesonet during the 1986, 1987 and 1988 data collection periods. The configuration of both networks, including the location of the radars and nearby airports, is shown in Figures 1 and 2, respectively.

Surface mesonet observations of microbursts were compared with the corresponding radar fields by expert humans to determine the probability that a microburst outflow was observable by the radar. This comparison addressed the possibility that an outflow was not observed by the radar due to:

- low SNR (signal-to-noise ratio),
- very shallow outflows for which the radar beam is too high above the surface,
- beam blockage or

Table 1. Characteristics of the 1986, 1987 and 1988 mesonet.

	1986			1987/88
	HUNTSVILLE			DENVER
	APR-MAY	JUN-JUL	AUG-SEP	JUN-OCT
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†

* Within 20 km to the north and west of the FL-2 radar

** Greater than 20 km to the north and west of the FL-2 radar

† Includes stations 1-28 and all LLWAS stations

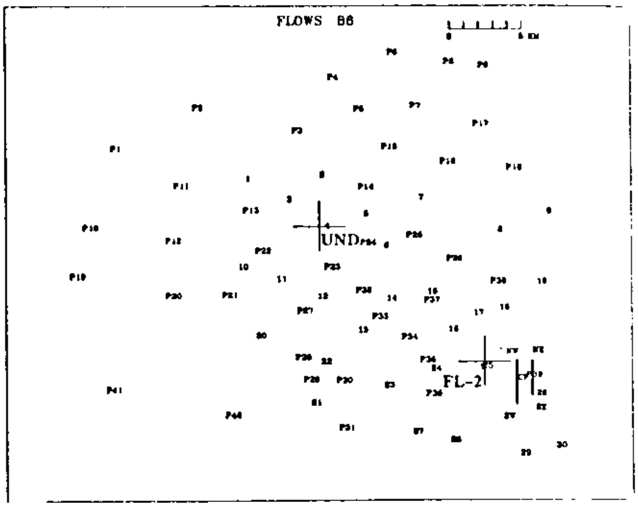

Figure 1. The 1986 TDWR testbed mesonet in Huntsville.

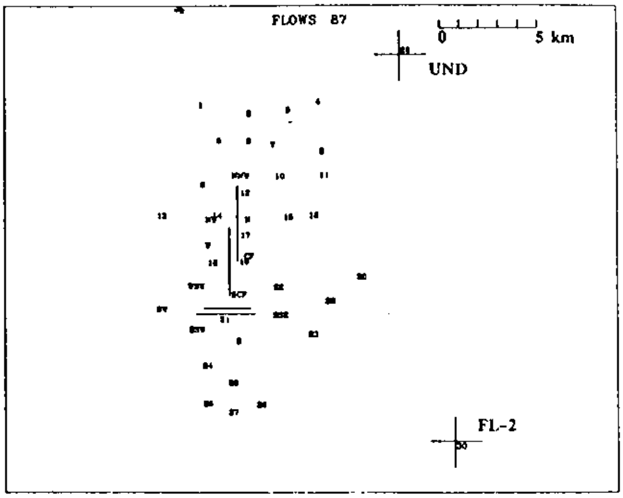

Figure 2. The 1987 and 1988 TDWR testbed mesonet in Denver.

- asymmetry in the surface outflow causing the radar to significantly underestimate the magnitude of the shear [Eilts and Doviak, 1987].

Also addressed was the possibility that microbursts were not observed by the mesonet because of:

- spacing between stations was too large, or
- microburst outflow did not reach the surface due to a dense layer of cold air.

The methodology of this comparison will now be summarized.

The FL-2 radar was used as the primary source of radar data for identifying microbursts. However, UND radar data was used when FL-2 data was not available, or if a microburst identified by the surface mesonet was not observed by FL-2. It should be noted that the scanning sequences used in 1986 often resulted in an update interval for surface scans of 4 to 5 minutes, instead of the desired one minute update interval. As a result, the observability of a small percentage of events was deemed inconclusive due to lack of temporal resolution, and such events were categorized with those for which radar data was not available. The scanning strategy during 1987 and 1988 in Denver provided a faster update rate of approximately once per minute for surface scans, thus minimizing this problem.

In order to be classified as a microburst, the divergent pattern had to exhibit 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. In addition, supporting evidence from the reflectivity field was required for the existence of a parent cloud for each microburst [Fujita, 1985]. Identification of the parent cloud was straightforward for Huntsville microbursts, but was not always obvious in Denver due to the presence of low- reflectivity or "dry microburst" events. In these cases, it was necessary to look aloft to clearly identify the parent cloud. It was possible to identify a parent cloud for every Denver event, except for a single case which occurred on 6 July 1987. In this case, a surface wind shear of 10-15 m/s was evident, but because the parent cloud could not be identified, this event was not classified as a microburst.

Surface mesonet data was processed as described in Wolfson et al, 1986. For each day, a 24-hour time series plot was produced for each station. These plots were analyzed to identify potential whind shear events. The primary indicator of a potential wind shear event 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 to classify an event as a microburst. However, due to the undersampling of the surface mesonet field, it is 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 shear exhibited the necessary horizontal shear of $2.5 \times 10^{-3} s^{-1}$. It was required that these criteria be attained for at least two minutes in order for the event to be classified as a microburst.

3.2 Pattern Recognition Performance Assessment

The performance of the microburst recognition algorithm was evaluated by comparing the microburst alarms generated by the algorithm from weather radar data with the results of detailed analysis of the radar data by experienced radar meteorologists. The role of the human analyst was to examine the weather radar data in an off-line environment to identify microbursts. The location, extent and strength of all identified microbursts were documented for each surface radar scan, which occured approximately once per minute. This database of microburst "ground truth" was then compared to the algorithm alarm output to determine detections, misses and false alarms. This manual analysis is an extremely time consuming task, and the evaluation described below is the result of several man-years of combined effort from scientists at Lincoln Laboratory and the National Center for Atmospheric Research (NCAR).

To achieve uniformity in the ground truth database, a commonly agreed definition of a microburst was needed. For this purpose, a microburst was defined as a divergent outflow region which exhibits a wind speed difference of at least 10 m/s over a distance of no more than 4 km. Note that the velocity difference may extend beyond the 4 km scale, so long as the required 10 m/s difference exists within some 4 km subregion. A microburst is considered ended when the velocity difference (over a 4 km scale) drops (and remains) below 10 m/s for a period of at least two minutes.

3.2.1 Rules for scoring against ground truth

To evaluate the performance of the algorithm, two basic quantities are desired: Probability of Detection (POD) and Probability of False Alarm (PFA). The POD is defined as the ratio of the number of events detected by the algorithm to the total number of events. The PFA is defined as the ratio of the number of false alarms to the total number of alarms.

These definitions relate performance to three fundamental concepts: an event, a detection and a false alarm. In this application, an event is defined as a single observation of an actual microburst by the radar on a low- elevation scan. Each actual microburst is typically observed on several sequential scans, and hence represents several events. Only those actual microbursts which fall within 30 km of the radar are considered in the scoring. An event is considered detected by the algorithm if the rectangle representing the event intersects any rectangle representing a microburst alarm from the algorithm. A microburst alarm from the algorithm is considered a false alarm if it does not intersect any rectangle representing an actual microburst event.

To provide an operationally realistic evaluation of the algorithm, certain alarms which would be strictly classified as false alarms are tallied separately. Declarations which overlap actual events which appear on radar scans within two minutes (before or after the current scan) are not considered false alarms, nor are any declarations which appear in the immediate vicinity (within 2 km) of actual microbursts considered false alarms. Also excluded are algorithm declarations which can be clearly traced to defects in the data acquisition system (e.g., ground clutter residue), which are not representative of the specified TDWR radar platform.

4. RESULTS

4.1 Radar Observability

During the 1986, 1987 and 1988 data collection seasons, it was estimated based on Doppler radar and surface mesonet data that 313 microbursts impacted the mesonet area. These microbursts were observed during the periods April 3 - December 9, 1986, June 6 - October 5, 1987 and July 1 - August 31, 1988, respectively.

Of these 313 known microburst events, 243 (77.6%) occurred when data were available from both the radar and mesonet surface sensors (Table 2 gives the statistics for each year). Of those 243 events:

- 218 (89.7%) were observed by both the radar and mesonet,
- 17 (7.0%) were unobserved by the mesonet surface sensors, and
- 8 (3.3%) were unobserved by the radar.

Thus, the radar observability percentage was 96.7%.

Table 3 categorizes the 243 microbursts according to their observed strength. Approximately 38% of these events were identified by maximum velocity differences of at least 20 m/s. The radar observation percentage for these stronger microbursts was 99% (91 of 92). Regarding the events that went unobserved, spacing of the mesonet stations was the cause of the mesonet misses (i.e., the network spacing was not dense enough), while several reasons accounted for the radar misses. For the 1988 data, one miss was due to outflow asymmetry and one miss was due to low SNR. For the 1987 data, low SNR was the cause of all four radar misses, and each was a low reflectivity or "dry" microburst. For the 1986 data, one radar miss due to asymmetry in the surface outflow and the other was due to the inability of the FL-2 radar to observe a very shallow outflow. Table 4 summarizes the causes of the failure to observe microburst events by the mesonet and radar.

Table 2. Mesonet impacting microburst statistics for 1986, 1987 and 1988.

	MESONET IMPACTING MB'S	RAD/MESO DATA AVAILABLE	OBSERVED BY BOTH RAD/MESO	UNOBSERV. BY MESONET	UNOBSERV. BY RADAR
1988	80	70	66	2	2
1987	102	66	61	1	4
1986	131	107	91	14	2
TOTAL	313	243	218	17	8

Table 3. Categorical distribution according to the strength of the mesonet impacting microbursts that occurred during 1986 in Huntsville and 1987 and 1988 in Denver when radar and mesonet data were simultaneously available.

	Maximum Differential Velocity (m/s)			
	<15	15 ≤ dV < 20	≥20	
1988	19	16	35	Number of Microbursts
1987	18	17	31	
1986	49	32	26	
TOTAL	86	65	92	

Table 4. Causes for microbursts impacting the 1986, 1987 and 1988 mesonet being unobserved.

UNOBSERVED EVENTS BY:	CAUSES 1986	CAUSES 1987	CAUSES 1988
RADAR	Asymmetry Shallow Outflow	Low SNR	Asymmetry Low SNR
MESONET	Spacing	Spacing	Spacing

Table 5 shows the radar observability by environment and microburst strength. The observability was 98.1% for all Huntsville microbursts and 95.6% for all Denver microbursts. It should be noted that the radar observability for Denver microbursts was improved in 1988 vs. 1987. One possible reason for this improvement was environmental variability in the proportion of dry microbursts. A second possible reason was the use of a lower surface elevation scan angle in 1988 enabled by the installation of a clutter map.

Table 5. Radar observability by environment and microburst strength.

Data	Microbursts	Radar Observability < 20 m/s	20+ m/s	All
Huntsville '86	107	97.5% 79/81	100.0% 26/26	98.1% 105/107
Denver '87	66	91.4% 32/35	96.8% 30/31	93.9% 62/66
Denver '88	70	94.3% 33/35	100% 35/35	97.1% 68/70
Denver '87/'88	136	92.9% 65/70	98.5% 65/66	95.6% 130/136
All data	243	95.4% 144/151	98.9% 91/92	96.7% 235/243

4.2 Pattern Recognition Performance

The performance of the microburst recognition algorithm was assessed for the Huntsville, AL and Denver, CO environments using the methodology outlined in section 3.2. The FL-2 radar data for five days from each environment were processed with the algorithm for a total of 126 microbursts. The probability of detection (POD) and probability of false alarm (PFA) were determined for a total of 1204 scans for which an alarm should have been generated for a given microburst, as determined by expert radar meteorologists.

The pattern recognition performance of the algorithm is summarized in Table 6. The probability of detection for all data was 91.5% and the false alarm rate was 5.2%. Moreover, the POD for strong events (20 m/s or greater) was 99.6%. Preliminary analysis for 1988 Denver data shows similar results to those shown in Table 6.

4.3 Combined Performance

Table 7 summarizes the combined performance of the prototype TDWR microburst detection system. For the Huntsville environment, the detection performance

Table 6. Microburst recognition algorithm performance.

Data	MBs	POD <20 m/s	20+ m/s	All	PFA
HSV '86	48	88.0%	100.0%	90.9%	5.3%
DEN '87	78	90.1%	99.4%	91.8%	5.2%
All Data	126	89.5%	99.6%	91.5%	5.2%

Note:

HSV '86: 7 June, 1 July, 25 June, 31 June, 21 Sep.

DEN '87: 23 May, 28 May, 30 May, 7 June, 10 June.

of the system for all microbursts is 89.2%. This value should be viewed as a conservative estimate of the TDWR system performance, since the scan strategies employed in Huntsville often did not provide the specified one minute update rate for surface scans, nor did the scanning aloft meet the TDWR requirements. For the Denver environment, the overall detection rate was 87.8%, primarily due to missed radar observations for low-reflectivity microbursts. As a result, the detection rate for the combined environments was 88.4%. However, it should be noted that the detection rate for strong microbursts was 98.5%.

Table 7. Combined microburst detection performance.

Data	Microburst detection < 20 m/s	20+ m/s	All
Huntsville '86	85.8%	100.0%	89.2%
Denver '87/'88	83.7%	97.9%	87.8%
All data	85.4%	98.5%	88.4%

5. SUMMARY

This paper has addressed the performance of the prototype TDWR microburst recognition algorithm using data from the TDWR testbed radar. The microburst recognition algorithm was outlined and the methodology for assessing performance was described. Two aspects of performance were assessed: radar detectability and pattern recognition. It was shown that over 96% of microbursts impacting a surface mesonet network were observed by radar, and that the radar observability of strong microbursts (20 m/s or greater) was over 98%.

It was also shown that the microburst recognition capability of the prototype algorithm was 92% probability of detection and 5% probability of false alarm when compared to single-Doppler truth as determined by expert meteorologists. Moreover, the probability of detection was over 99% for strong microbursts.

The combined performance of the microburst detection system was found to be 88%, and the detection performance was better in Huntsville than in Denver. The detection performance in Huntsville was degraded by the scan strategies employed in 1986, which did not always provide the specified one minute update rate for surface scans. This deficiency in the scan strategy impaired the microburst recognition performance for Huntsville. By contrast, the detection performance in Denver was primarily degraded by failures in the radar observation of weak microbursts with low-reflectivity. However, it should be noted that the radar observability in Denver was improved in 1988 over 1987, and that modifications were also made to the prototype algorithm during 1988 to improve its performance. The effect of these changes is currently being further evaluated and will be reported subsequently. However, it is clear from the current results that the detection performance is 98% or better for strong microbursts in either environment.

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