A PROTOTYPE MICROBURST PREDICTION PRODUCT FOR THE TERMINAL DOPPLER WEATHER RADAR *

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1. INTRODUCTION

This paper describes a prototype microburst prediction product for the Terminal Doppler Weather Radar (TDWR). The prediction product was evaluated for microbursts observed during the spring and summer of 1989 at Kansas City. Results are presented demonstrating reliable prediction of high reflectivity microbursts of at least 15 m/s outflow intensity from single-Doppler radar data. The ability of the algorithm to predict microbursts approximately five minutes prior to the onset of surface outflow could be used to improve air traffic control (ATC) planning and to improve hazard warning time to pilots. In particular, this product could allow aircraft to avoid an impending microburst hazard, rather than penetrating it.

The present TDWR microburst recognition algorithm uses features aloft such as reflectivity cores and convergence to recognize microburst precursors. The algorithm uses precursors to make a microburst declaration while the surface outflow is still weak, thereby improving the hazard warning time (Campbell, 1989). The microburst prediction product is an extension of the algorithm to predict microbursts from these precursor signatures. The prototype prediction product is tuned to predict the high reflectivity microbursts typical of humid regions of the United States.

The paper begins by reviewing conceptual models for microburst development and comparing them to the observed characteristics of Kansas City microbursts. The prototype prediction product is then described, and performance statistics are presented. Finally, failure mechanisms and future work are discussed.

2. MICROBURST PRECURSORS

Research in Colorado (Fujita and Wakimoto, 1983, Roberts and Wilson, 1989, and Biron and Isaminger, 1989), Oklahoma (Eilts, 1987), and Alabama (Isaminger, 1987) identified precursors to microbursts such as descending reflectivity cores, mid-level rotation and convergence, reflectivity notches, upper-level divergence and lower-level divergence. Conceptual models were developed by Fujita and Wakimoto (1983), Roberts and Wilson (1989), and Campbell (1988) to describe the storm evolution prior to a microburst outflow. The model for high reflectivity microbursts developed by Roberts and Wilson (1989) encompasses the vast majority of Kansas City microbursts. In this model, the combination of an increasing radial convergence at or near cloud-base and a descending reflectivity core was deemed a good radar indicator of a downdraft. The presence of rotation or reflectivity notches in combination with either of the above features was also considered a microburst precursor.

The characteristics of a typical Kansas City microburst producing cell were determined based on an examination of radar data for 18 events reaching a magnitude of 15 m/s or greater. As shown in Table 1, the most reliable feature was a descending high reflectivity core, which was observed in over 90% of the cases. Cyclonic rotation, anticyclonic rotation, convergence, and upper divergence were observed in three-quarters of the events. Kansas City microbursts were just as likely to be preceded by rotation and upper divergence as convergence.

The lead times from Table 1 were used to develop a conceptual model for the evolution of a typical Kansas City microburst. In the early stage of development, an updraft is indicated by the upper-level divergence at T-9 (i.e., nine minutes prior to the surface outflow initially reaching 10 m/s). At T-7, rotation is first observed in the cell at mid-levels. The reflectivity core descends at T-5 minutes, shortly after convergence is apparent within the core.

Of the features aloft observed, the descending reflectivity core was the most reliable indicator of downdraft onset. The lead time for the observation of descending cores had a standard deviation of 2.3 minutes. There was greater variability in the lead time for the mid- and upper-level velocity features, with standard deviations ranging from 4.7 to 5.7 minutes.

3. PRODUCT DESCRIPTION

The microburst recognition algorithm relies on the ability of the TDWR to scan both at the surface for microburst outflows and aloft in the parent cloud for features associated with microbursts, as shown in Figure 1 (Campbell, 1988). Features aloft associated with microbursts include high reflectivity cores, mid-level convergence and rotation, and upper-level divergence. These features aloft can be used

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Table 1. Radar observables in Kansas City microburst producing cells. Percent occurrence, lead time prior to onset of surface outflow and standard deviation, based on 18 microbursts reaching 15 m/s.

Radar Feature	% Occur.	Lead time (min.)	Std.Dev. (min.)
Upper divergence	72.2	9.0	5.7
Cyclonic rotation	77.8	7.0	4.7
Anticyclonic rot.	77.8	7.0	5.5
Convergence	77.8	5.8	5.7
Descending core	94.4	5.0	2.3

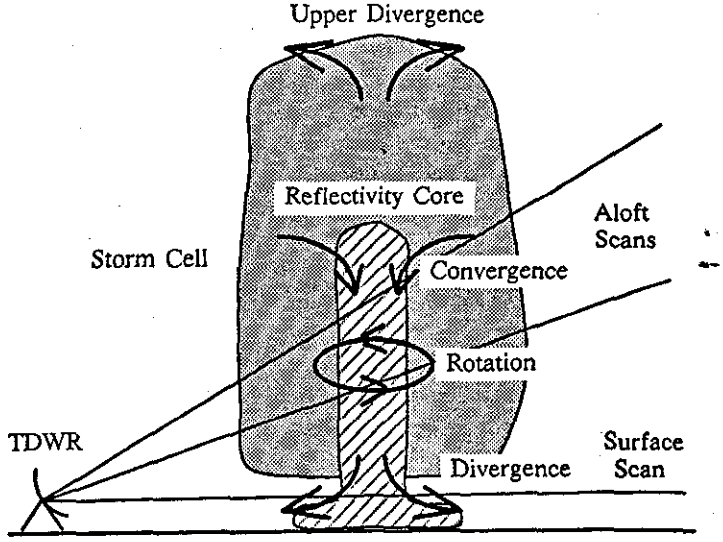

Figure 1. Illustration of TDWR scanning at surface for microburst outflows and aloft in parent storm for features associated with microbursts.

to both confirm the existence of a microburst outflow and to predict a future microburst outflow.

The current TDWR microburst recognition algorithm detects microburst precursor signatures which typically precede the surface outflow by five to ten minutes. The criteria for declaring a microburst precursor are that a reflectivity core must be detected along with a mid-level convergence, mid-level rotation (cyclonic or anticyclonic) or upper-level divergence. The reflectivity core must meet certain site adaptable criteria, such as a minimum height of 4.5 km and a maximum reflectivity of at least 54 dBZ. In addition, one of two additional criteria must be satisfied: either the reflectivity core must be descending, or a convergence (or rotation) must extend below 3.5 km altitude. These criteria are intended to detect the presence of a strong downdraft which will lead to a microburst outflow at the surface.

Microburst precursor signatures are used in the current algorithm to increase the timeliness of microburst declarations (Campbell, 1989). Normally, the microburst algorithm must wait until a microburst outflow is detected on successive surface scans spaced one minute apart, and the second outflow must be at least 10 m/s (20 knots). However, when a precursor signature is detected the microburst can be declared when the initial, weak (< 10 m/s) surface outflow is detected.

The microburst prediction product is a simple extension of the existing microburst precursor recognition capability. The first time that a precursor is detected for a particular event, a microburst prediction is issued for five minutes in the future at the precursor location. This prediction is counted down for each subsequent surface scan (once per minute) until either the microburst occurs or a total of seven minutes elapse. The prototype prediction product does not predict the strength of the outflow, although the site adaptable parameters are intended to predict those microbursts reaching at least 15 m/s (30 knots) intensity.

It should be pointed out that the current version of the prediction product is aimed at predicting high reflectivity microbursts of the type commonly found in the Southeast United States. This type of microburst activity is expected to predominate at practically all airports scheduled for TDWR deployment, except for dry environments such as Denver which are characterized by low reflectivity events.

4. PERFORMANCE STATISTICS

The prototype microburst prediction product was tested using data from the FL-2 TDWR testbed radar operated by Lincoln Laboratory at Kansas City during the summer of 1989. The algorithm performance was assessed for eleven days between 14 May and 28 August on which microbursts occurred. Only those cells which developed in the airport sector and within 35 km of the FL-2 radar were considered (see Figure 2). A microburst was defined as a 10 m/s or greater radial divergence either at the surface or below 1 km AGL, as observed by either the S-band FL-2 radar or the C-band UND radar operated by the University of North Dakota.

The results of this assessment are shown in Table 2. A total of 89 microburst events were examined, 36 of which reached 15 m/s intensity. The product successfully predicted 61% (22 of 36) of the microbursts that reached 15 m/s. There were 45 microburst predictions issued, of which 40 (89%) resulted in microbursts of at least 10 m/s, and 5 (11%) were false alarms. The median time from initial prediction to onset of surface outflow was 5.0 minutes with a standard deviation of 2.8 minutes.

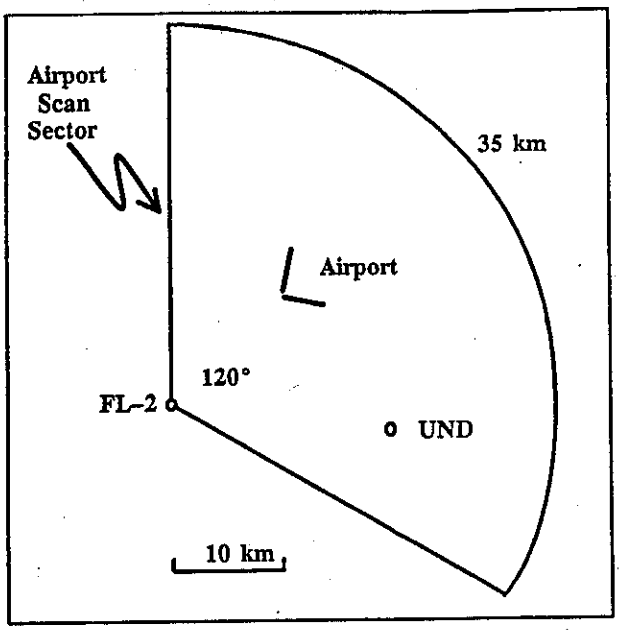

Figure 2. Radars used in 1989 Kansas City operation.

Table 2. Kansas City Microburst Prediction Product Statistics.

Number of events	89
Number of events ≥ 15 m/s	36
Number of events ≥ 15 m/s successfully predicted	22 (61%)
Number of predictions issued	45
Number of valid predictions (≥ 10 m/s outflow)	40 (89%)
Number of false predictions	5 (11%)
Median prediction lead time (minutes)	5.0
Standard deviation of prediction lead time (minutes)	2.8

Of the 40 valid predictions, there were two which did not reach 10 m/s from the FL-2 perspective, but did from the UND perspective. A likely cause of the difference in observed intensities is asymmetry in the microburst outflow. There were two additional events which exhibited divergence above the surface but below 1 km AGL. These events may be instances of the microburst divergence not reaching the surface due to a shallow layer of cold air from a previous outflow. These results suggest a potential use for features aloft in compensating for outflow asymmetry and the detection of mid-air microbursts.

Figure 3 summarizes the velocity features aloft that were found by the algorithm when microburst predictions were made (note: more than one velocity feature may be identified by the algorithm for a particular event). Cyclonic or anticyclonic rotation was found for slightly more than half of the predicted events. Convergence was detected in 30% of the cases, while upper-level divergence was seldom used to make a prediction. Reflectivity cores were identified in all cases (as required by the current algorithm), however, the core was identified as descending in only one-half of the cases. When compared to Table 1, these results suggest that the current algorithm does a credible job in detecting rotation, but needs improvement in the detection of mid-level convergence and upper-level divergence, and in the ability to declare cores as descending.

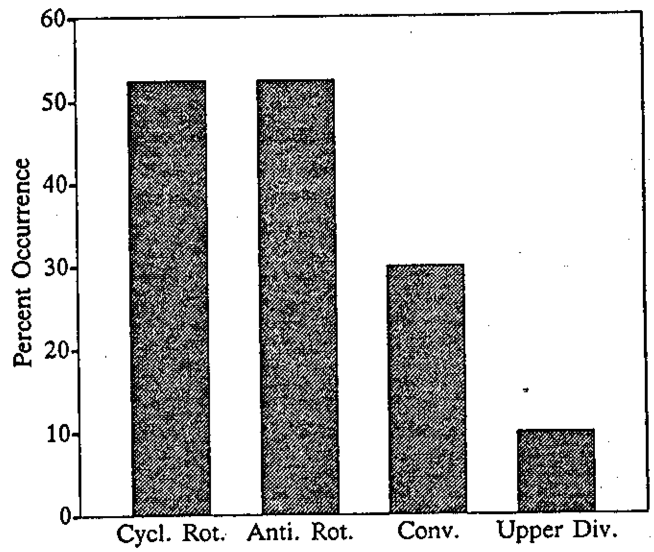

Figure 3. Velocity features aloft identified by algorithm when microburst predictions were made (percent occurrence for 40 cases).

5. FAILURE MECHANISMS

In this section, the failure mechanisms of the algorithm will be examined. Three of the fourteen microbursts which were not predicted exceeded a velocity differential of 20 m/s. Therefore, it is important to further analyze these so that improvements can be made to the prediction product.

As seen in Figure 4, half of the missed predictions were because the reflectivity core did not attain the maximum height threshold of 4.5 km. Other causes for missed predictions were: no reflectivity core detected, overlap with a preexisting microburst, not attaining the maximum reflectivity threshold, and no velocity feature detected. It appears that there is a class of lower reflectivity Kansas City microbursts which did not meet the current criteria for precursor declaration.

Further analysis of the prediction product performance suggests that the criteria used for reflectivity core height (4.5 km) and maximum reflectivity (54 dBZ) may be too restrictive for the Kansas City environment. These criteria were

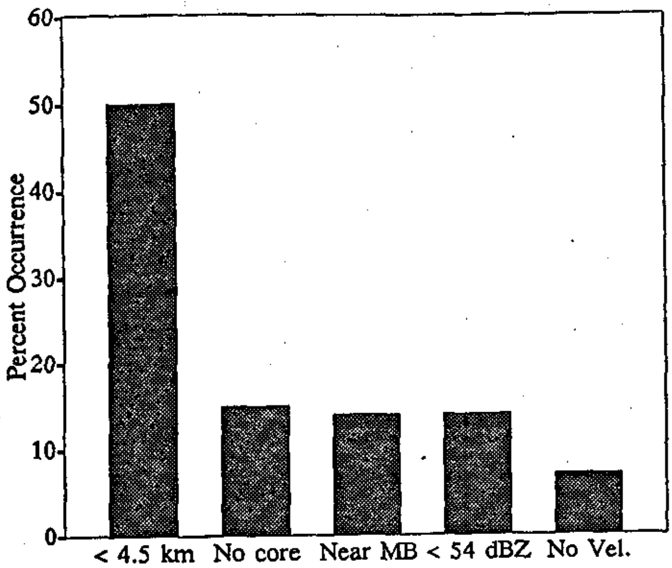

Figure 4. Reason for missed predictions of Kansas City microbursts (percent occurrence for 14 cases).

developed based on an earlier examination by Isaminger (1987) of microbursts in the Huntsville, AL area. It was found that the core height threshold could not be lowered without causing an unacceptable increase in false alarms. However, lowering the reflectivity threshold to 51 dBZ would increase prediction POD to 67% without impacting the false alarm rate.

To reduce false predictions, 40% could be eliminated by reducing the threshold for the lower altitude limit on velocity features from 3.5 to 2.7 km. It should be noted that such criteria as core height, maximum reflectivity and velocity feature lower altitude limit are parameters which can be adjusted on a site-adaptable basis to optimize performance.

6. FUTURE WORK

There are several areas for future work on the prediction product. As noted above, the current product does not predict low reflectivity microbursts typical of dry environments such as Denver, since these events are not associated with high reflectivity cores. Also, one-half of the microbursts not predicted in Kansas City were lower reflectivity events. It is possible that an extension of the algorithm to use moderate- and low-reflectivity structures (also recognized by the current algorithm) may allow these events to be predicted.

The current product does best at predicting isolated microbursts, and performance decreases whenever multiple outflows occur in close proximity, such as along a squall line or in large storm complexes. After the dèscent of the initial reflectivity core, the algorithm has difficulty in recognizing secondary descending cores associated with reintensifying or pulsating outflows. Work has begun at Lincoln in examining the use of features aloft in combination with detected surface outflows to predict microburst reintensification.

Other areas for future work are to improve the accuracy of prediction time and to add outflow strength prediction. Work has begun at Lincoln on the use of storm liquid water content to improve prediction time accuracy, and to potentially provide microburst strength and trend estimates.

7. SUMMARY

A prototype TDWR microburst prediction product was developed as an extension to the existing TDWR microburst recognition algorithm. This product was evaluated in the Kansas City environment and shown to predict over 60% of microbursts reaching 30 knots intensity. The average lead time from initial prediction to onset of surface outflow was five minutes. Of the predictions issued, nearly 90% resulted in microbursts of at least 20 knots intensity. Thus, favorable performance was demonstrated in a wet environment likely to be representative of most TDWR installation sites. It was shown that minor changes to site adaptable parameters could improve the prediction rate and reduce false predictions.

Further testing of the product will be conducted at Orlando, FL during the summer of 1990. Plans for these tests include operational evaluation of the prediction product by ATC personnel, and real-time display in the cockpit of an experimental aircraft. Longer-term work is planned to improve prediction of lower reflectivity events, and to include microburst strength prediction and trend estimation.

8. REFERENCES

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