USING FEATURES ALOFT TO IMPROVE TIMELINESS OF TDWR HAZARD WARNINGS

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1. INTRODUCTION

The Terminal Doppler Weather Radar (TDWR) has an operational requirement to provide a one minute advance warning for aircraft encountering a hazardous wind shear. This paper describes the use of features aloft in the prototype TDWR microburst recognition algorithm to improve the timeliness of microburst hazard warnings. The use of features aloft allows the algorithm to make a microburst declaration while the surface outflow is still weak, thereby increasing the hazard warning time. In addition, current work indicates that these signatures can also be used to predict the onset of surface outflow for high-reflectivity events.

An initial version of the microburst recognition algorithm using surface velocity data only was described by Merritt (1987). Initial work on the use of features aloft to increase the reliability and timeliness of microburst alarms was described in Campbell, 1988. This work was motivated by the desire to emulate the ability of human experts to use features aloft to enhance the timeliness of microburst warnings (McCarthy & Wilson, 1986). This research was further influenced by the conceptual models for the evolution of low, medium and high reflectivity microburst events in the Denver area proposed by Roberts and Wilson (1986), and by studies of features aloft associated with microbursts in the Southeast (Isaminger, 1987). The current TDWR microburst recognition algorithm is described in Campbell and Merritt, 1988.

The present paper presents results demonstrating the ability of the prototype algorithm to recognize features aloft for microburst events observed at Huntsville, AL and Denver, CO. It is shown that the ability to recognize features aloft improved the hazard warning time for these events. Initial results for microburst prediction are also presented.

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2. MICROBURST RECOGNITION

In order to meet the TDWR requirement of providing a one minute warning for hazardous microburst wind shears, the recognition algorithm should detect outflows before they reach hazardous intensity. In order to provide a timely warning for hazardous outflows, the TDWR scan strategy provides for a surface scan every 60 seconds and the algorithm is required to have at least 90% probability of recognizing outflows of 10 m/s or greater on any scan, while maintaining a probability of false alarm of 10% or less.

Figure 1 illustrates a typical microburst event. We define the start of the microburst event to be the first surface scan for which the surface outflow exceeds the alarm threshold of 10 m/s, and a microburst warning is generated if the alarm is 15 m/s or greater. The end of the microburst event is defined as the last outflow above the alarm threshold before the outflow goes below the alarm threshold for at least two minutes.

The alarm timeliness is defined by the difference between the event start time and the initial alarm declaration. For the example shown, the alarm timeliness is 1 minute, since the initial alarm declaration was made one minute prior to the outflow reaching the alarm threshold. Similarly, the precursor timeliness is defined by the difference between the event start time and the initial precursor detection. For the example of Figure 1, the precursor timeliness is five minutes.

If no features aloft are present, the microburst recognition algorithm requires two successive surface outflows to be detected, with the second outflow having a velocity of at least 10 m/s. For the example of Figure 1, the algorithm would declare the microburst at t = 0, assuming that surface divergence features of 8 m/s and 11 m/s were detected on succeeding scans.

However, if the 11 m/s feature was detected but the 8 m/s feature was not detected, then the first declaration of the microburst event would be delayed until the next scan, causing a one minute decrease in alarm timeliness. If the microburst algorithm finds a surface divergence

MICROBURST EVENT TIMING

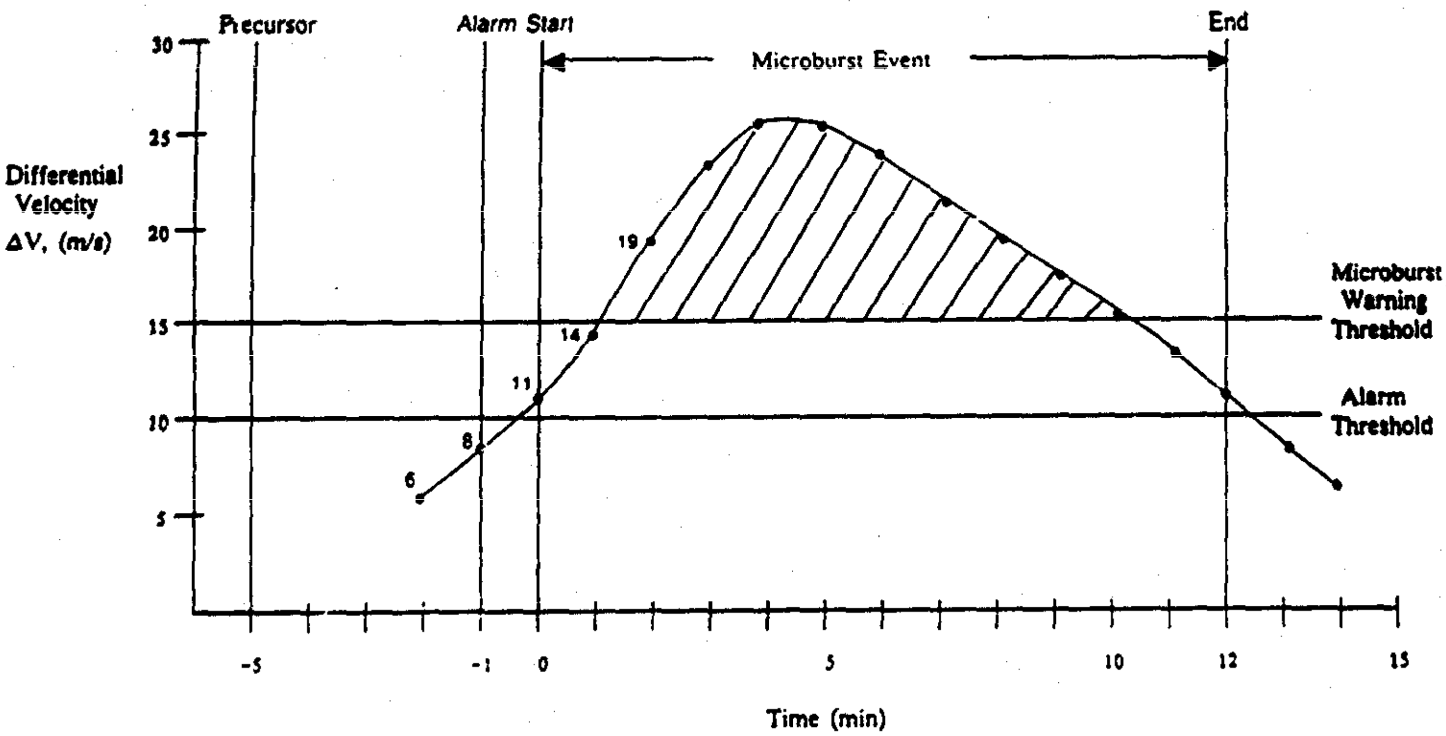

Figure 1. Microburst Event Timing

feature which is at least 10 m/s but is not preceded by any surface outflow feature, then features aloft are used to attempt to make the alarm declaration. If such a surface divergence feature overlaps:

- a reflectivity core, or

- a rotation or convergence aloft extending below 3.5 km AGL, or

- a lower divergence (divergence above surface but below 1 km AGL), or

- a divergence aloft (divergence above 7 km AGL),

then the microburst alarm is declared. Thus, the timeliness of the alarms can be maintained even if the initial, subthreshold outflow is not detected.

Furthermore, the algorithm can also make an early declaration of the microburst event based on a weak surface outflow (< 10 m/s) accompanied by a microburst precursor. Three types of microburst precursor signatures are currently recognized:

- a descending reflectivity core and any convergence aloft, rotation aloft, lower divergence or divergence aloft, or

- a reflectivity core and a convergence or rotation aloft extending below 3.5 km AGL, or

- a descending convergence or rotation aloft.

A descending reflectivity core is declared when the lower altitude limit of a reflectivity core descends below 2 km AGL; a descending convergence or rotation is declared when its lower altitude limit and centroid descend below 3 km AGL. In either case, the structure is declared as descending until it falls below 0.5 km AGL.

If a surface divergence feature is weak (i.e. between 7.5 and 10 m/s) and it overlaps a detected precursor, then the microburst event is declared without waiting for the outflow to reach the alarm threshold. For the example of Figure 1, the microburst would be declared when the outflow is 8 m/s, improving the timeliness of the warning by one minute.

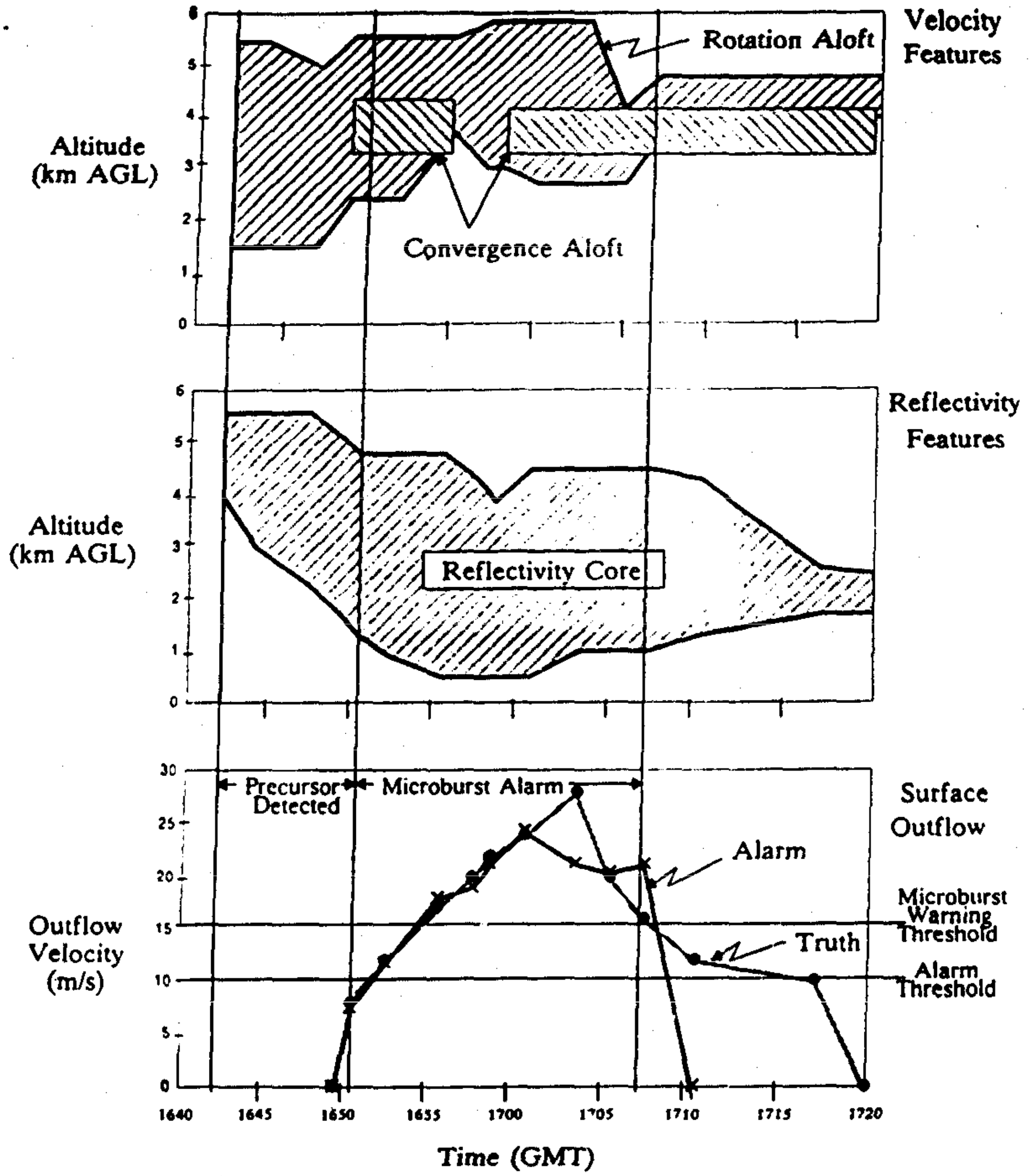

Figure 2. ***Surface outflow and features aloft for microburst #1 on 7 June 1986 at Huntsville, AL.***

To illustrate this procedure, consider the case shown in Figure 2. This microburst occurred on 7 June 1986 at Huntsville, AL. The bottom graph shows the time course of the surface outflow as determined by the algorithm and by human experts. As seen in the figure, the match between the algorithm and expert generated truth is quite good during the first half of the event, and that the event is detected at all times when the velocity exceeds the microburst warning threshold.

The upper two graphs of Figure 2 show the velocity and reflectivity features aloft detected by the algorithm. The lower and upper altitude limits for each structure are shown as a function of time. The initial microburst precursor declaration is made at about 1642Z based on the rotation aloft which extends from 1.5 to 5.5 km AGL and the reflectivity core which extends from 4.0 to 5.6 km AGL. The reflectivity core is seen to descend over the next nine minutes, reaching 1.3 km AGL by 1651Z when the initial surface outflow of 8 m/s is observed. Convergence aloft is also detected at this time from 3.3 to 4.6 km AGL.

Based on the precursor signature detected from the reflectivity core and the rotation aloft, the algorithm is able to declare the microburst at at 1651Z instead of the succeeding scan, resulting in an increase in microburst timeliness of over one minute. Also, the precursor declaration for this case preceded the initial outflow above 10 m/s by about ten minutes.

3. PERFORMANCE ASSESSMENT

The performance of the microburst algorithm was assessed on data gathered by the FL-2 S-band radar operated by Lincoln Laboratory at Huntsville, AL in 1986 and at Denver, CO in 1987. Five days of data from each location were used and ground truth was established for 126 microburst events, as explained in Campbell, Merritt & DiStefano, 1989.

3.1 Microburst Alarm and Precursor Detection Timeliness

The timeliness of microburst alarms for the 126 events was determined for the prototype algorithm operating with and without features aloft, as shown in Table 1. As defined in section 2.0, a positive timeliness value indicates that the alarm preceded the scan for which the outflow exceeded 10 m/s. As seen in the table, the use of features aloft increased the timeliness of microburst alarms by an average of 0.3 minutes. It is seen from Table 1 that the timeliness improvement due to the use of features aloft was greater for Huntsville microbursts than for Denver events.

The events of Table 1 were further classified by maximum reflectivity associated with the surface outflow: high (55+ dBZ), moderate (35 - 54 dBZ) or low (< 35 dBZ). Table 2 shows the alarm timeliness by reflectivity class. It is seen that the greatest improvement in timeliness occurred for high reflectivity events. Because 79% of the Huntsville events were high reflectivity, as opposed to only 13% of the Denver events, the increase in timeliness was proportionally greater for the Huntsville events.

A further study was made to determine the timeliness of precursor detection. Precursors were detected for 27 of the 126 microburst events. In order to determine the timeliness of precursor detection, it is necessary to consider only the first event to occur in a particular region, since precursor declaration is suppressed if a earlier microburst is detected in the same area. Of the 27 events for which precursors were detected, seven such events were found, and the precursor and alarm timeliness for these events is shown in Table 3.

The average precursor warning time for the seven events was 6.2 minutes, which corresponds well with the conceptual model for high reflectivity events proposed by Roberts & Wilson, 1986. The alarm timeliness for these events was also compared with and without features aloft. It was found that the use of features aloft increased the alarm timeliness for these events by 1.3 minutes. This result is consistent with results previously reported for a single event (Campbell, 1988).

Table 1. Microburst alarm timeliness in minutes by geographic location.

Data	Events	Surface Only	Features Aloft	Timeliness Improvement
Huntsville '86	48	+0.1	+0.5	+0.4
Denver '87	78	+0.1	+0.3	+0.2
All Data	126	+0.1	+0.4	+0.3

Table 2. Microburst alarm timeliness in minutes by event reflectivity.

Reflectivity	Events	Surface Only	Features Aloft	Timeliness Improvement
High	48	0.0	+0.5	+0.5
Medium	43	+0.3	+0.3	0.0
Low	35	+0.1	+0.2	+0.1
All Data	126	+0.1	+0.4	+0.3

Table 3. Timeliness of precursor and surface outflow declaration.

Date	Start (GMT)	Surface Only	Feat. Aloft	Improve -ment	Precursor Warning
7 JUN 86	165147	0.0	+1.3	+1.3	+10.1
25 JUL 86	220825	-1.8	-0.8	+1.0	+6.0
31 JUL 86	185523	-0.9	0.0	+0.9	+5.7
23 MAY 87	210023	-3.4	-2.5	+0.9	+6.3
	212500	0.0	+2.6	+2.6	+4.7
	212944	0.0	0.0	0.0	+4.8
	213635	0.0	+2.3	+2.3	+5.9
Average (7 events)		-0.9	+0.4	+1.3	+6.2

All of the events in Table 3 were classified as high reflectivity. However, the improvement in alarm timeliness was greater for these events than for high reflectivity events in general. Since precursors were only detected for 20 of the 48 high reflectivity events (note: precursors were not detected for some events due to inappropriate scanning), it would be expected that the alarm timeliness for all high reflectivity events would be proportionately degraded. Applying this assumption, we arrive at the observed timeliness improvement of 0.5 minutes for all high reflectivity events.

3.2 Precursor Detection Performance

A subset of the 126 events were further examined to determine whether features aloft were present prior to the onset of the surface outflow. A feature aloft was defined to be present if one or more of the following signatures were present in the radar data: descending local reflectivity maximum, mid-level rotation, mid-level convergence or divergent top. A local reflectivity maximum was considered to be descending if it formed above 3 km AGL and descended below this level to the surface. Rotation, convergence and divergence signatures were constrained to have a velocity differential of at least 10 m/s. Rotation and convergence were looked for in the altitude range of 1-6 km AGL, and divergent tops were required to be at least 6 km AGL in altitude.

Microburst events which were beyond 30 km, closer than 5 km, not scanned to at least 4.5 km AGL or not scanned at least 5 minutes prior to onset of surface outflow were discarded from further consideration at this stage. The surviving 68 microburst events were classified according to their maximum reflectivity: low (< 35 dBZ), moderate (35 to 54 dBZ) or high (55+ dBZ), as shown in Table 4. Next, the presence of microburst features aloft under the criteria stated in the previous paragraph was determined as a function of microburst reflectivity. As seen in Table 4, it was found that the presence of microburst features aloft was a strong function of microburst reflectivity. While 93% of the high reflectivity events had features aloft, this figure reduced to 62% for moderate reflectivity events and only 35% for low reflectivity events.

Thus, high reflectivity events seem to nearly always have features aloft preceding the surface outflow, according to the definitions presented above. By contrast, low reflectivity events have these signatures much less often. There are several possible explanations for this observation. First, the definitions were developed primarily for high reflectivity events in Huntsville and include several types of signatures which never occur for low reflectivity events, such as divergent tops. Second, there is some evidence that velocity signatures tend to be weaker in the Denver environment, so the requirement of 10 m/s velocity may discriminate against Denver microbursts, which tend have lower reflectivity than Huntsville events. Finally, it appears from field experience that the features aloft for low reflectivity events are simply less obvious and harder to interpret than those for high reflectivity events.

Table 4. Feature aloft presence vs. event reflectivity.

Data	Events	Microburst Reflectivity High	Microburst Reflectivity Med.	Microburst Reflectivity Low	Features Aloft Present High	Features Aloft Present Med.	Features Aloft Present Low
Huntsville '86	25	19	6	0	17	5	0
Denver '87	43	8	15	20	8	8	7
All Data	68	27	21	20	25	13	7
Percentages					93%	62%	35%

The ability of the prototype algorithm to declare microburst precursors as a function of event reflectivity is shown in Table 5 for 104 events. It was found that the algorithm provided a microburst precursor declaration for 53% of the high reflectivity events, 21% of the moderate reflectivity events and 6% of the low reflectivity events. For high reflectivity events, it was found that precursor detection often failed because the reflectivity core was not detected. In order to increase the detection of reflectivity cores, the threshold for identifying high reflectivity features has now been reduced from 50 dBZ to 45 dBZ but the impact of this change has not been fully evaluated.

Table 5. Microburst precursor detection vs. event reflectivity.

Data	Events	Microburst Reflectivity High	Microburst Reflectivity Med.	Microburst Reflectivity Low	Precursor Detected High	Precursor Detected Med.	Precursor Detected Low
Huntsville '86	31	23	8	0	10	2	0
Denver '87	73	9	30	34	7	6	2
All Data	104	32	38	34	17	8	2
Percentages					53%	21%	6%

It should be noted that the current algorithm can only detect descending reflectivity maxima for high reflectivity events. Some work has been done on detecting the descent of moderate and low reflectivity storm cells, but these methods have not progressed far enough for use the algorithm. Completely addressing this problem is viewed as requiring additional techniques to identify local reflectivity maxima and to adaptively process regions of stratiform precipitation.

4. SUMMARY

This report has described the improvement in microburst alarm timeliness with the use of features aloft. To date, the results are most promising for high reflectivity events. It has been shown that the microburst alarm timeliness for the first event in a particular area is increased by over a minute with the use of features aloft. Because microbursts often occur in groups, the declaration of the first event in a series is important, since there is no prior indication of a hazard. The development of a precursor product would also be useful, since it could be used to increase pilot vigilance for developing microburst hazards.

In examining the initial results, it appears that the detection of microburst precursors for high reflectivity events is immature but reasonably promising. Our work thus far suggests that the features aloft are almost always present for this type of microburst event, such as a reflectivity core accompanied by convergence aloft, rotation aloft or divergent top. Moreover, we have found that the thresholding method currently employed works reasonably well for detecting reflectivity cores.

There are several areas for future work. First, additional work needs to be done to increase the precursor detection rate for high reflectivity events. It is anticipated that this work will lead to the demonstration of a microburst prediction product for high reflectivity events. Second, further work needs to be done in the area of detecting precursors for moderate and low reflectivity events. In particular, it may be necessary to adjust algorithm thresholds for the Denver environment and to investigate additional reflectivity processing methods. Third, initial work has begun on using features aloft to predict outflow strength and duration. It is anticipated that such factors as storm structure and magnitude of velocity features aloft will play important roles in this work. Finally, the performance of the microburst algorithm needs to be evaluated for NEXRAD operated as an interim TDWR.

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