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MICROBURST DIVERGENCE DETECTION FOR TERMINAL DOPPLER WEATHER RADAR

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1. INTRODUCTION

The Federal Aviation Administration (FAA) is currently procuring a Terminal Doppler Weather Radar (TDWR) system, to provide aviation users with information regarding potentially hazardous weather phenomena, particularly microburst windshear. This warning system is completely automated, and relies on computer algorithms for the detection of windshear signatures in the radar data. The TDWR microburst detection process makes use of radar measurements from both surface radar scans and from scans aloft. The surface scans are used to identify microburst outflows; the scans aloft provide information concerning reflectivity and velocity structures associated with microbursts to improve recognition rate and timeliness.

The detection of surface divergence regions is crucial to the performance of the system, and is the focus of this paper. The current detection algorithm has been carefully evaluated against a very large set of measured microburst cases, including those recorded during a real-time operational demonstration conducted during July-August 1988. The operation of the divergence algorithm is described below, along with the results of extensive performance analysis.

2. ALGORITHM DESCRIPTION

2.1 3-D detection algorithm

The TDWR microburst detection algorithm relies primarily on the detection of microburst outflows (divergence) in the radar velocity field measured near the surface. When a divergence region is detected which exhibits time continuity (is seen on two consecutive radar surface scans) and is above the microburst alarm threshold (10 m/s velocity differential), a microburst alarm is generated. Significant storm features detected aloft may also be used by the system to generate microburst alarms when weaker divergence regions are seen at the surface, or when they are first detected (Figure 1) [Campbell and Merritt, 1988].

2.2 Divergence region detection

The divergence detection algorithm attempts to locate two-dimensional regions of divergent shear, based on radial velocity measurements from the radar. The algorithm operates by scanning each radial of velocity measurements to locate shear segments (runs of contiguous velocity values which exhibit a generally increasing trend with range), and then associating these segments across adjacent radials of the radar sweep (Figure 2) [Merritt, 1987].

The shear segments are identified by sliding a window out in range (typically 0.5 km in extent*), and declaring the start of a segment when the velocity values in the window are monotonically increasing. Having found the start of a segment, the end is found by moving the window out further in range until either of the following segment termination criteria are met:

i) More than 3/4 of the sample points in the window are invalid measurements (i.e., below signal power threshold) or have a velocity value less than the value at the first point in the window

ii) The difference between the velocity value at the start of the window and at that point with the smallest velocity greater than that at the start of the window exceeds 15 m/s.

As the window is moved out in range searching for the segment endpoint, the 'next' starting point for the window is chosen to be the first point in the window such that the difference between the velocity value at that point and the current window starting point is both non-negative and less than 50% greater than the minimum non-negative difference from the current starting point to all points in the window. In this manner, the window starting point moves through a series of increasing velocity points, but avoids 'latching' onto spurious peaks in the data.

Once a segment has been found by the above process, it subjected to a series of validation tests. These tests reject segments which do not exhibit a consistent increas-

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* Note that all numerical values cited in this description are formally documented as 'site adaptable parameters' and may therefore be adjusted to optimize performance of the system at each TDWR installation.

ing trend, and trim the segment start and endpoints back to insure that they are reasonable local extrema and have adequate slope (shear). The validation test sequence for a segment may be expressed as follows:

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Do until segment is accepted or rejected:
    Trim the start and end points back (towards center of segment) until the velocity difference over a 0.5 km distance is at least 1.25 m/s at both ends of the segment.
    Trim the start and end points back until each is a local extrema.
    If segment is too short (less than 950 meters), reject it.
    Check that the running mean velocity value (averaged over 0.5 km) is strictly monotonically increasing along the length of the segment. If not, reject it.
    Check the start and end points to verify that each is within 5 m/s of the local median velocity value (computed over 1 km). If both points meet this criteria, accept the segment. Otherwise, trim each point not meeting the criteria back one gate, and repeat the validation loop.
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Those segments which survive these validation tests are then associated across radar azimuths to form two-dimensional regions of shear. Any two segments which exhibit adequate overlap in range (at least 0.5 km) and are within 2 degrees in azimuth are joined together into the same region. This association process continues until all segments have been labeled into regions. These aggregates are now thresholded based on their total area, number of segments, and maximum segment strength. Regions with area less than 1 square km, fewer than 2 segments, or having a maximum velocity differential (across the strongest segment in the cluster) less than 5 m/s are discarded. The result of this clustering process is a set of 'significant' regions of divergent shear, which are then passed to the 3-D vertical association and time continuity modules.

3. PERFORMANCE ASSESSMENT

3.1 *Methodology*

The performance of the microburst detection algorithm has been evaluated through an extensive data collection and analysis program. The alarms generated by the detection system are evaluated by a comparison to 'ground truth' information, derived by detailed human analysis of the base radar observations. In some cases, the availability of a second Doppler radar has allowed ground truth information to be based on objective analysis of dual-Doppler windfields as well.

Whether based on dual-Doppler windfield analysis, or manual observation of single-Doppler radial windfields, the ground truth database contains the location, extent, and strength of each microburst present in the radar data. This information is recorded for each surface scan of the radar (once per minute). By comparing the information in the ground truth database with the actual alarms issued by the detection system, the system performance may be computed, in terms of correct detections, missed events, and false alarms.

Throughout the algorithm development and evaluation effort, a microburst has 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 sub-region. 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.

This manual analysis is an extremely time consuming task, and the evaluation described here is the result of several man-years of combined effort from scientists at Lincoln Laboratory and from the National Center for Atmospheric Research (NCAR).

3.2 *Data cases used in the evaluation*

Ground truth analysis has been performed for a number of data cases from the TDWR Operational Test and Evaluation program in 1988. During this demonstration, the FL-2 Doppler weather radar [Evans and Johnson, 1984] was located in the Denver, CO area and operated every afternoon during the summer months. Both single and dual-Doppler analyses have been performed. The single Doppler ground truth was developed primarily by Lincoln analysts, while the dual-Doppler truth analysis was performed by researchers at NCAR [Mahoney et. al., 1988]. Table 1 lists the days for which ground truth has been completed for the 1988 cases. Additional cases are in the process of being analyzed and refined.

3.3 *Performance statistics*

A careful comparison has been performed between the single-Doppler ground truth cases listed in Table 1 and the TDWR microburst alarms generated during the same period. In this comparison process, the area of intersection between alarms and truth outlines is computed, and used to decide if individual alarms are correct or false (and whether true events were detected or not). The results of this comparison are shown in Table 2. This table lists the total number of actual events (i.e., radar observations of microbursts) and the number of these events which were detected by the system. These statistics are broken down into weak and strong events, being those with total velocity differentials of <15 m/s and >15 m/s, respectively.

These performance results indicate that detection performance on strong events is nearly perfect (97%), with a somewhat lower detection rate (77%) for weaker microbursts. The probability of false alarm (i.e., the probability that an alarm which was issued by the system does not correspond to an actual microburst event) was 5%. Note that these statistics indicate how well microbursts were detected on a scan-by-scan basis, and not on an event-by-event basis. The microburst detection algorithm rarely misses a microburst over its entire lifetime; of the 40 microbursts used for the statistics presented here, only 4 were entirely missed by the algorithm (90% detection rate). These events were very weak (average velocity difference was 12 m/s) and lasted for only a few minutes each. Additional performance characteristics, including a comparison of system-generated alarms with observations from a surface wind network, are included in [Campbell et. al., 1988].

A detailed comparison of microburst alarms to the dual-Doppler ground truth is in progress, but has not yet been completed. Results of this comparison are expected to indicate performance very similar to that obtained using single-Doppler ground truth.

4. Future Work

The development and operational evaluation of microburst detection techniques is a major component of both the Weather Radar program at Lincoln Laboratory, and the Research Applications Program at NCAR. The primary goals for near-term improvements to the microburst divergence detection algorithm include:

1) examination of data pre-filtering techniques for reducing the effects of localized interference sources, such as aircraft,
2) the use of temporal feedback in the low-level shear detection process, to stabilize the detection of events after they are first identified, and
3) the potential use of alternative divergence region identification techniques which may provide more reliable detection on weak events or those whose outflow strengths vary with radar viewing angle.

Additional research into microburst forcing mechanisms and precursors, as well as aircraft response to microburst wind shears, will be addressed in the ongoing cycle of TDWR development and refinement of the automated detection techniques, to keep pace with meteorological understanding of the microburst phenomena.

6. Acknowledgments

The work described in this paper is the result of the cumulative effort of numerous people over the last several years. The 1988 microburst ground truth analysis was performed by: Mark Isaminger, Daniel Hutton, and Charles Curtiss from Lincoln Laboratory, and Marsha Politovich, F. Wesley Wilson, and William Mahoney of NCAR. Performance assessment against this ground truth was accomplished by Darelyn Neilley and Richard DeLaura, and the strength accuracy analysis was performed by Robert Hallowell.

7. References

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Date	No. Microbursts	Truth type
June 10	17	single
June 21	20	single
June 25	12	single
July 02	46	dual
July 07	10	single
July 09	10	dual
July 11	15	dual
July 16	49	dual
July 17	6	single
July 29	9	dual

Table 1: Microburst ground truth cases for 1988

Date	True Events Strong	True Events Weak	Detected Events Strong	Detected Events Weak
10 June 88	59	37	56	28
21 June 88	45	36	44	32
25 June 88	70	19	69	16
7 July 88	46	48	43	32
17 July 88	39	1	38	1
Totals	259	141	250	109

POD (weak) = 250/259 = 97%
POD (strong) = 109/141 = 77%
POD (overall) = 359/400 = 90%
PFA = 21/417 = 5%

Table 2: Microburst performance results for 1988 single-Doppler ground truth cases.

POD = "Probability of Detection"
PFA = "Probability of False Alarm"

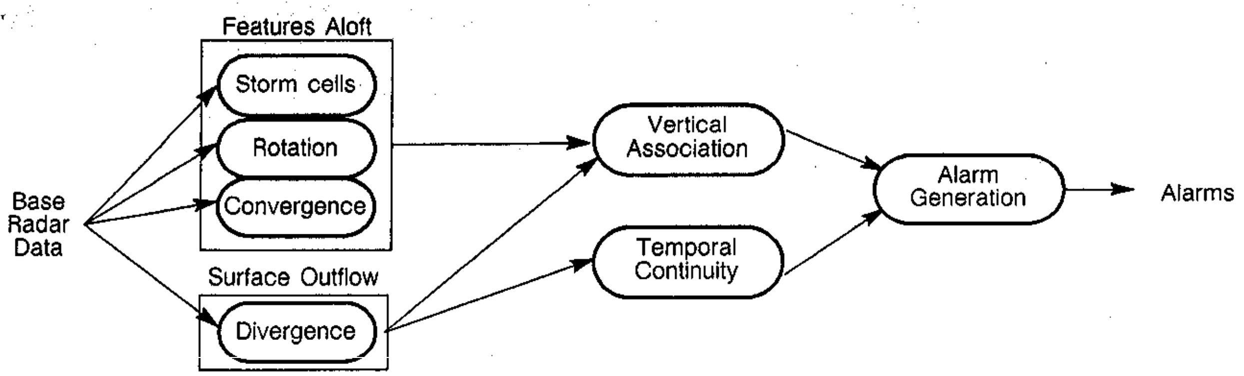

Figure 1: 3-D microburst detection algorithm

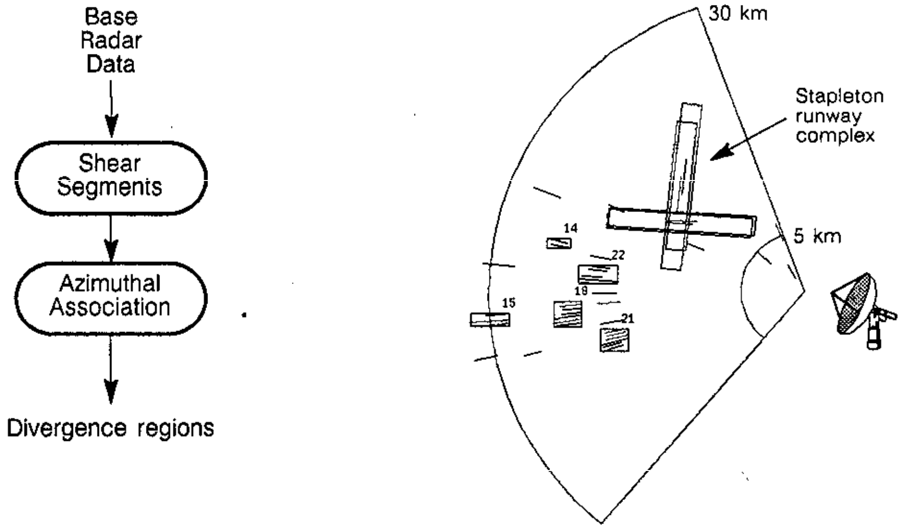

Figure 2: Divergence region detection algorithm, and example from 1988 testing at Denver. Plot at right shows raw shear segments identified by the shear search process, while boxes represent the accepted divergence regions, after azimuthal association.

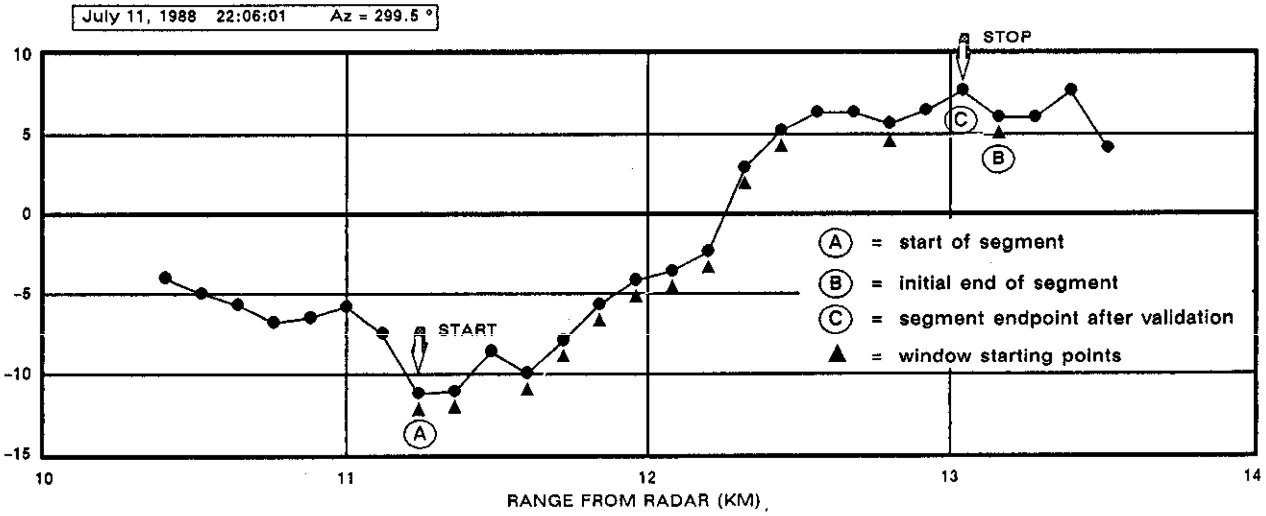

Figure 3: Shear segment detection example