A SHEAR-BASED MICROBURST DETECTION ALGORITHM FOR THE INTEGRATED TERMINAL WEATHER SYSTEM (ITWS)

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1. INTRODUCTION

Microbursts are small scale, low altitude wind shear phenomena which caused a number of recent aircraft accidents. Microbursts arise from thunderstorm downdrafts which impact the earth's surface and produce a strong divergent outflow of wind. They are often associated with heavy rainfall (Wolffson, 1988).

The Terminal Doppler Weather Radar (TDWR) program was the first attempt at automated microburst detection with a ground-based Doppler weather radar in the airport terminal area. Improving safety is its primary goal, and test operations in Denver, Kansas City, and Orlando have shown it highly successful in identifying microbursts. The algorithm output is a series of elongated "band aid" shapes which cover the identified hazardous region. In general, identification has been performed with a > 90% Probability of Detection (POD) and a < 10% Probability of False Alarms (PFA) (Campbell and Olson, 1987).

The Integrated Terminal Weather System (ITWS) seeks to enhance this ability by providing earlier warnings to facilitate microburst avoidance by pilots and improved terminal planning. Microburst predictions will be produced in addition to detections (Wolffson et al., 1993). A microburst trend product, giving predictions of increasing microburst intensity along runway corridors over short time periods (2-3 minutes), will facilitate pilot decision making by providing explicit information on the expected evolution of a microburst over the time interval between receipt of a warning and encounter of the microburst. This product will require the ability to predict the future location, size, and intensity of the microburst. The microburst trend product and the need to consider the nature of the warnings that will be generated by airborne windshear detection systems requires enhancements to the TDWR microburst detection algorithm.

Although the TDWR algorithm successfully detects the area of hazard, the output representation provides no insight into the number of events present and suggests uniform shear within the microburst. Improvements need to be made if the TDWR microburst alarms are to be used for tracking microbursts. The ITWS algorithm attempts to improve tracking by providing one output shape for each downdraft. The TDWR alerting is fundamentally loss based, that is, the severity of the hazard is indicated by the strength of the surface divergence coupled. However, if this divergence is not over a small area, an aircraft will experience little or no performance deficit. The ITWS algorithm captures this information by examining the divergence shear (rate of change in velocity) as well as the loss. Ground-based doppler radar observation has shwon, and instrumented aircraft penetrations have confirmed (Matthews and Berke, 1993, Campbell et al., 1992) that the shear within a microburst is highly nonuniform. The ITWS algorithm will use an additional, embedded warning shape to indicate especially hazardous regions of a microburst.

This paper explains the initial design of the ITWS microburst detection algorithm and illustrates some early results. The final section concentrates on the plans for algorithm testing and the planned enhancements to its capabilities.

2. ALGORITHM DESIGN

The algorithm is comprised of four primary elements: radial shear calculation, segment formation, region formation, and alarm generation. The algorithm is intended to find microbursts, and weaker wind shear events, out to a 30 km range, but 55 km is actually processed to alleviate edge effects. Surface scans from the TDWR are available approximately every minute. The ITWS microburst algorithm will process all scans equal to, or below 1.0 degrees elevation angle.

![Figure 1](image-url) (Illustration of shear calculation as doppler velocity on a single radial varies. The slope of the heavy line is assigned as the shear value.)

The radial shear is calculated as the spatial derivative of the radial velocity field. The base velocity data is first median filtered, using a range adaptive filter size (approximately 1km by 1km), and a least squares fit of a line segment to the data is performed as in Figure 1. The slope of the fit line segment is written as the radial shear at that gate. Both the median filtering and the regression fitting output a valid value only if at least a certain percentage (currently 50%) of base velocity values are above the signal-to-noise threshold.

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The segment forming module processes the radial shear map to locate contiguous segments along a radial above a set of user-defined thresholds. Currently, two thresholds, 5.0 m/s/km (low shear) and 10.0 m/s/km (high shear) are used. The segment must meet a minimum length to be considered valid. Each valid segment is then extended until either (a) the average shear along its length falls below the threshold, (b) a gate with a negative shear value is encountered, or (c) an excessive number of consecutive invalid shear values are found. In this way, a segment is not considered unless a minimum shear is present, but the length of the segment is not rigidly tied to the points above threshold. The loss (velocity difference) across the segment is calculated over a different scale, found as the maximum segment length while the average shear remains above 2.5 m/s/km, or until conditions (b) or (c) are found.

![Image](image_url)

Figure 2. Depiction of Segment forming process. The final segment endpoint II was placed by condition (a), and endpoint II was placed by condition (b).

The Region formation module processes the set of shear segments at each threshold level into regions of high shear. Regions are built by associating segments on adjacent radials which overlap by a user-defined percentage. A circular shape is fit to the segments of the region using an optimization technique. The parameters of the circle (center x, center y, radius) are chosen to minimize the sum of the minimum distance from each segment end to the circle perimeter and the distance of the segment end to the circle center. The optimization is unidimensional (each parameter is optimized one at a time), since it was determined that the extra computation for a multidimensional technique was unnecessary. The region is discarded if a minimum number of segments is not included or if the area of the best fit circle is below a threshold. Regions from the high and low shear threshold levels are associated together if the percent area of intersection is higher than a user-defined amount. Those high shear regions without an accompanying low shear region are discarded.

The low shear regions are passed through a final alarm generation test. If the maximum loss from any segment in a region is greater than 15 m/s (30 knots) and the peak shear within the region is greater than 10.0 m/s/km, a microburst alert is generated. If both of these criteria are not met a wind shear alert is generated if the maximum loss exceeds 8 m/s (15 knots) and the shear is greater than 5.0 m/s/km. Finally, a candidate outflow is tracked internally in the algorithm if the shear region exceeds only one of the wind shear thresholds. All high shear regions associated with the alarm regions are output as separate highlighted areas for display.

3. RESULTS

The algorithm has thus far been executed on 12 microburst cases, using TDWR test bed data collected from Orlando (8 cases), Kansas City (2 cases), and Denver (2 cases). On this data set it has demonstrated that it can at least match the performance of the TDWR algorithm in identifying microbursts and quantifying their intensity. Additional studies are necessary to ensure that the false alarm rate is also comparable.

The additional goals of a more accurate downdraft identification and output shape consistency as an aid to tracking have produced mixed results. Isolated events, such as that shown in Figure 3, 4, and 5 are successfully characterized as originating from single downdrafts. As a result, the algorithm is successful in assigning event labels and following a consistent track over the lifetime of the event. Situations with multiple, interacting downdrafts are currently identified more erratically. This originates from an improper identification of the downdrafts, and results in difficult to interpret apparent merging and splitting of events. Recent evidence about the correlation between peak shear locations and downdrafts, and additional aloft information which will be integrated from the ITWS microburst prediction algorithm (Wolfson et al., 1993) indicate that this problem can be alleviated in the near future.

![Image](image_url)

Figure 3. The loss and peak shear values over the course of an Orlando, 1990 microburst, as determined by the ITWS Microburst Detection algorithm.
Figure 4. The location track of the same microburst event as in Figure 3. The center of the circle output by the ITWS algorithm is used as the location, and the truth has been determined by hand by an expert meteorologist.

4. PLANS

The ITWS algorithm will be tested in real-time in the ITWS testbed site in Orlando, Florida from 5/93 through 9/93. This is expected to give us a large dataset for the inevitable modification and fine tuning of the algorithm. The ITWS microburst prediction and microburst trend algorithms will also be running in Orlando, beginning 7/93. This will help clarify the potential advantageous interactions between the algorithms.

We expect to make several enhancements to the algorithm in the next calendar year. Other sensors are to be examined, particularly the Low Level Wind Shear Alert System (LLWAS), for integration with the ITWS algorithm. This will ensure that a consistent single alert is made for the entire terminal area. Attempts will be made to compensate for microburst asymmetry and adjust for aircraft altitude in microburst intensity warnings. Also, information of the kind the ITWS microburst prediction algorithm is considering (Wolfson et al., 1993), will be used to provide a more accurate identification of the strength and location of the downdraft. This is important, since the vertical winds near the ground are not captured by low elevation angle ground based radar scans, and the downdraft is also a source of significant hazard for an aircraft.

5. REFERENCES


Figure 5. Comparison of (a) TDWR and (b) ITWS algorithm shapes for time 20:17 in the event of Figure 3 and 4. A high shear region is cross-hatched within the outer ITWS shape.