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Improvement in Gust Front Algorithm Detection Capability using Reflectivity Thin Lines versus Azimuthal Shears*

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1. INTRODUCTION

Gust front detection is of concern for both Terminal Doppler Weather Radar (TDWR) and Next Generation Weather Radar (NEXRAD) systems. The automatic detection of gust fronts is desirable in the airport terminal environment because warnings of potentially hazardous gust front-related wind shears can be delivered to arriving and departing pilots. Information about estimated time of arrival and accompanying wind shifts can be used by an Air Traffic Control (ATC) supervisor to plan runway changes. Information on expected wind shifts and runway changes are also important for terminal capacity programs such as Terminal Air Traffic Control Automation (TATCA; Spencer, *et al.*, 1989) and wake vortex advisory systems. In addition, the convergence associated with gust fronts is often a factor in thunderstorm initiation and intensification. Knowledge of their locations and strengths can aid forecasters with thunderstorm forecasts.

Experienced radar meteorologists can identify gust fronts in single Doppler radar data by the presence of radial convergence, azimuthal shear, and thin lines of reflectivity (Klingle, 1985). The radial convergence signature is the most reliable of all of the signatures. Therefore, the formally-documented TDWR gust front algorithm is designed to automatically detect gust fronts through radial convergence.

The current TDWR gust front algorithm and its ability to detect gust fronts has been documented in Smith, *et al.*, 1989; Klingle-Wilson, *et al.*; 1989, and Evans, 1990. Although the probability of detecting gust front events is typically 70%, shortcomings with the algorithm have been noted. These shortcomings include the inability of the algorithm to detect gust front events as they pass over the radar or become aligned along the radar beam and detecting only part of the event. These deficiencies often become more significant as an event approaches an airport.

Conventional wisdom supports the opinion that the radial convergence-finding technique used in the algorithm is optimized and that algorithm performance can be improved only by taking advantage of other radar signatures, namely reflectivity thin lines and azimuthal shears. Given that there are limited resources for investigating these approaches, the purpose of the study was to determine which other signature would provide the greater benefit in terms of improvement in algorithm performance.

In the following discussion, a gust front **event** is a single observation (on a volume scan) by the NSSL ground-truth analyst of a gust front in the radar data. A **detection** is an algorithmic declaration of a gust front that overlaps ground truth. All gust front events that were located within 60 km of the radar were truthed.

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2. METHODOLOGY

The analysis was divided into two parts. The objective of the first part was to assess if events that were missed by the algorithm would have been detected by incorporating thin line and/or azimuthal shear detection in the algorithm. The objective of the second part was to determine whether identification of thin lines and/or azimuthal shears would have improved the performance of the algorithm on those events the algorithm had already detected. Events were categorized according to strength, as characterized by the change in radial wind across the events (ΔV). Events were defined as weak ($5\ m/s \leq \Delta V < 10\ m/s$), moderate ($10\ m/s \leq \Delta V < 15\ m/s$), strong ($15\ m/s \leq \Delta V < 25\ m/s$), and severe ($\Delta V \geq 25\ m/s$). Single Doppler data collected in Denver during 1988 (7 days) and in Kansas City during 1989 (11 days) were used for the analysis. The dates are given in Table 1.

Table 1. Dates of Gust Front Data used in Analysis

Denver 1988	Kansas City 1989
4 July	27 March
10 July	28 April
11 July	18 May
14 July	25 May
16 July	3 June
17 July	18 June
18 July	24 June
	26 June
	10 July
	12 July
	15 August
229 Detections	301 Detections
117 Misses	112 Misses

These data represent 530 detected and 229 missed events. The Denver and Kansas City data were analyzed separately to determine the sensitivity to geographical location.

The radar data were overlaid with algorithm detections and ground truth. Ground truth was generated by experts during real time and off-line operations and included all events that were longer than 10 km. All events on each tilt were subjectively divided into five parts, each part representing 20% of the total length. The number of parts with radial convergence, azimuthal shear, and thin line were recorded. In addition, a subjective assessment was made of which signature (azimuthal shear or thin line) would provide the greater performance improvement.

The analysis of missed events focused on whether radial convergence of less than 10 km plus a) thin line, b) azimuthal shear, or c) both thin line and azimuthal shear would have resulted in a detection.

Gust front truth was composed of radial convergence, azimuthal shear and/or reflectivity thin line. The combination of these features resulted in a gust front truth at least 10 km long. The initial assumption was that if radial convergence was present in the event, it would be detected by the algorithm. The reason no gust front detection was declared was because the actual radial convergence did not exceed the algorithm minimum length threshold (10 km). In this context, azimuthal shears and thin lines would add on to the gust front extent identified by radial convergence and thereby improve the chances that the algorithm length threshold would be exceeded.

The analysis of detected events determined:

1. How much the detection would have been improved (in terms of percent of length detected) with the use of thin line.
2. How much the detection would have been improved with the use of azimuthal shear.

3. RESULTS

3.1. Missed Events

The results of the analysis of missed events for Denver and Kansas City are provided in Table 2 and Table 3, respectively. Part A of the tables shows the number of events for each strength, with signatures including azimuthal shear, reflectivity thin line, neither azimuthal shear nor thin line, and both azimuthal shear and thin line. The **Total** column indicates the number of events of each strength involved in the analysis, and the **No Conv.** column gives the number of events with no radial convergence signature. Part B presents the estimated increase in percent of total event length over radial convergence attributable to azimuthal shears and thin lines, respectively. Part C provides the assessment of which signature would give the greater performance improvement.

Part A of Table 2 and Table 3 indicates that 24% of the Denver and 35% of the Kansas City missed events exhibited neither thin line nor azimuthal shear features. Thus, the assumption that the algorithm had detected all of the radial convergence is probably invalid. This suggests that algorithm performance could be improved by implementing a better radial convergence-finding technique. If those missed events that exhibited only radial convergence had been detected, the Probability of Detection (POD) for the Kansas City and Denver data used herein would have increased by 9%.

There were 8 gust front truths that contained no radial convergence. These could be detected only by the use of azimuthal shear or thin line. The use of azimuthal shear, in addition to radial convergence, might have resulted in the detection of about 48% (sum of **Azimuthal Shear** and **Both** columns) of the Denver and 50% of the Kansas City missed events. Use of thin lines in addition to radial convergence might have resulted in the detection of 66% (sum of **Thin Line** and **Both** columns) of the Denver and 44% of the Kansas City missed events. Although the use of azimuthal shears would improve algorithm performance equally in Denver and Kansas City, the results show that the use of thin lines would improve algorithm performance in Denver more than in Kansas City.

Part B of Table 2 shows that in Denver about 50% of the lengths (exclusive of radial convergence) of missed events could be identified by either azimuthal shear or thin line when these signatures were present. In Kansas City (Table 3, Part B), 57% of the event length could be identified by azimuthal shear and 43% by thin line.

Part C of Table 2 and Table 3 provides the assessment of which signature would provided the greater im-

Table 2. Results of Analysis of 1988 Denver Missed Events

(A)

STRENGTH	NUMBER OF EVENTS WITH: AZIMUTHAL SHEAR ONLY	THIN LINE ONLY	BOTH[1]	NEITHER[2]	TOTAL	NO CONV.
WEAK	6	27	24	14	71	4
MODERATE	3	5	17	11	36	4
STRONG	3	1	3	3	10	
ALL	12 (10%)[3]	33 (28%)	44 (38%)	28 (24%)	117	8 (7%)

(B) (C)

STRENGTH	PERCENT OF EVENT LENGTH (EXCLUSIVE OF RADIAL CONVERGENCE) ATTRIBUTABLE TO: AZIMUTHAL SHEAR # OBS	AZIMUTHAL SHEAR AVG. %	THIN LINE # OBS	THIN LINE AVG. %	NUMBER OF CASES WHERE GREATER IMPROVEMENT WAS PROVIDED BY: AZIMUTHAL SHEAR	THIN LINE	EQUIVALENT IMPROVEMENT FOUND
WEAK	29	50%	21	50%	7	43	21
MODERATE	22	53%	19	51%	3	19	14
STRONG	5	44%	2	40%	4	3	3
ALL	56	50%	42	50%	14	65	38

1 Both azimuthal shear and reflectivity thin line signatures were present
2 Neither azimuthal shear nor reflectivity thin line signatures was present
3 ( ) = Percent of total

Table 3. *Results of Analysis of 1989 Kansas City Missed Events*

(A)

STRENGTH	NUMBER OF EVENTS WITH: AZIMUTHAL SHEAR ONLY	THIN LINE ONLY	BOTH[1]	NEITHER[2]	TOTAL	NO CONV.
WEAK	3	12	8	12	35	2
MODERATE	9	4	20	22	55	13
STRONG	10	1	4	4	19	3
SEVERE	2			1	3	
ALL	24 (21%)[3]	17 (15%)	32 (29%)	39 (35%)	112	18 (16%)

(B) (C)

STRENGTH	PERCENT OF EVENT LENGTH (EXCLUSIVE OF RADIAL CONVERGENCE) ATTRIBUTABLE TO: AZIMUTHAL SHEAR # OBS	AZIMUTHAL SHEAR AVG. %	THIN LINE # OBS	THIN LINE AVG. %	NUMBER OF CASES WHERE GREATER IMPROVEMENT WAS PROVIDED BY: AZIMUTHAL SHEAR	THIN LINE	EQUIVALENT IMPROVEMENT FOUND
WEAK	11	49%	11	27%	4	17	14
MODERATE	29	68%	18	53%	15	14	26
STRONG	14	54%	4	40%	1		9
SEVERE	5	20%			1		2
ALL	59	57%	33	43%	21	31	51

1 Both azimuthal shear and reflectivity thin line signatures were present
2 Neither azimuthal shear nor reflectivity thin line signatures was present
3 ( ) = Percent of total

provement in algorithm performance. In Denver, the preferred signature was thin lines. In Kansas City, there was no substantial difference in performance between the signatures. These results are summarized in Table 4.

The potential increase in POD from the use of azimuthal shears or thin lines can be estimated if one assumes that the detection of either (in addition to convergence) would result in the detection of the event. The potential increase in POD using a better convergence-finding technique is 9% for both Denver and Kansas City. The potential increase in POD using azimuthal shear and convergence is 16% for Denver and 13% for Kansas City and 22% and 12%, respectively, using thin line and convergence.

3.2. Detected Events

Table 5 and Table 6 present the results of the analysis of detected events for Denver and Kansas City, respectively. Part A of the tables shows the number of events for each strength whose detections would have improved with the use of azimuthal shear, reflectivity thin line, neither azimuthal shear nor thin line, and both azimuthal shear and thin line. The **Total** column indicates the number of events

Table 4. *Comparison of Denver and Kansas City Missed Events*

	DENVER	KANSAS CITY
PERCENT OF CASES EXHIBITING POTENTIAL IMPROVEMENT IN DETECTION WITH ADDITION OF:		
AZIMUTHAL SHEAR	48%	50%
THIN LINE	66%	44%
PERCENT OF EVENTS WITHOUT AZIMUTHAL SHEAR AND/OR THIN LINE SIGNATURES	24%	35%
PERCENT OF EVENT LENGTH (EXCLUSIVE OF CONVERGENCE) ASSOCIATED WITH:		
AZIMUTHAL SHEAR	50%	57%
THIN LINE	50%	43%
POTENTIAL INCREASE IN POD USING:		
IMPROVED CONVERGENCE-FINDING	9%	9%
CONVERGENCE AND AZIMUTHAL SHEAR	16%	13%
CONVERGENCE AND THIN LINE	22%	12%
BEST SIGNATURE	Thin Line	No Significant Difference

Table 5. Results of Analysis of 1988 Denver Detected Events

(A)

STRENGTH	NUMBER OF EVENTS WITH: AZIMUTHAL SHEAR ONLY	THIN LINE ONLY	BOTH[1]	NEITHER[2]	TOTAL
WEAK	3	23	8	34	68
MODERATE	5	24	11	57	97
STRONG	2	7	17	37	63
SEVERE		1			1
ALL	10 (4%)[3]	55 (24%)	36 (16%)	128 (56%)	229

(B) (C)

STRENGTH	PERCENT OF EVENT LENGTH (EXCLUSIVE OF RADIAL CONVERGENCE) ATTRIBUTABLE TO: AZIMUTHAL SHEAR # OBS	AZIMUTHAL SHEAR AVG. %	THIN LINE # OBS	THIN LINE AVG. %	NUMBER OF CASES WHERE GREATER IMPROVEMENT WAS PROVIDED BY: AZIMUTHAL SHEAR	THIN LINE	EQUIVALENT IMPROVEMENT FOUND
WEAK	10	30%	26	51%	1	5	2
MODERATE	17	12%	36	35%	1	9	1
STRONG	19	27%	24	39%	5	10	2
SEVERE			1	10%			
ALL	46	22%	87	41%	7	24	5

1 Both azimuthal shear and reflectivity thin line signatures were present
2 Neither azimuthal shear nor reflectivity thin line signatures was present
3 ( ) = Percent of total

Table 6. Results of Analysis of 1989 Kansas City Detected Events

(A)

STRENGTH	NUMBER OF EVENTS WITH: AZIMUTHAL SHEAR ONLY	THIN LINE ONLY	BOTH[1]	NEITHER[2]	TOTAL
WEAK	4	13	2	40	59
MODERATE	10	59	21	42	132
STRONG	16	22	5	35	78
SEVERE	12			20	32
ALL	42 (14%)*	94 (31%)	28 (9%)	137 (46%)	301

(B) (C)

STRENGTH	PERCENT OF EVENT LENGTH (EXCLUSIVE OF RADIAL CONVERGENCE) ATTRIBUTABLE TO: AZIMUTHAL SHEAR # OBS	AZIMUTHAL SHEAR AVG. %	THIN LINE # OBS	THIN LINE AVG. %	NUMBER OF CASES WHERE GREATER IMPROVEMENT WAS PROVIDED BY: AZIMUTHAL SHEAR	THIN LINE	EQUIVALENT IMPROVEMENT FOUND
WEAK	6	14%	11	45%	1	1	
MODERATE	24	23%	67	36%	5	13	3
STRONG	11	15%	31	32%	2	3	
SEVERE	12	31%					
ALL	53	22%	109	36%	8	17	3

1 Both azimuthal shear and reflectivity thin line signatures were present
2 Neither azimuthal shear nor reflectivity thin line signatures was present
3 ( ) = Percent of total

of each strength involved in the analysis. Part B presents the estimated increase (over radial convergence) in percent of total event length detected that was attributable to azimuthal shears and thin lines, respectively. Part C provides the assessment of which signature would give the greater performance improvement.

Part A of the tables shows roughly half (56% in Denver and 46% in Kansas City) of the detections would not have been improved by the use of either thin line or azimuthal shear. It is possible that detection might be improved through an enhanced convergence-finding technique. Part A also shows that 40% of the Denver and Kansas City event detections could have been improved with the use of thin line detection. (These percentages are computed by summing the **Thin Line** and **Both** columns.) For azimuthal shear, these values are 20% and 23%, respectively (**Azimuthal Shear plus Both columns.**)

Part B of the tables indicates that the greatest improvement in percent of length detected was associated with thin lines for both Kansas City and Denver. The subjective assessment (Part C) supports this observation. These results are summarized in Table 7.

Table 7. Comparison of Denver and Kansas City Detected Events

	DENVER	KANSAS CITY
PERCENT OF CASES EXHIBITING POTENTIAL IMPROVEMENT IN DETECTION WITH ADDITION OF:		
AZIMUTHAL SHEAR	20%	23%
THIN LINE	40%	40%
PERCENT OF EVENTS WITHOUT AZIMUTHAL SHEAR AND/OR THIN LINE SIGNATURES	56%	46%
ESTIMATED INCREASE IN PERCENT OF LENGTH DETECTED DUE TO:		
AZIMUTHAL SHEAR	22%	22%
THIN LINE	41%	36%
BEST SIGNATURE	Thin Line	Thin Line

4. CONCLUSIONS

Information on gust front locations, strengths and associated wind shifts is useful for planning runway configurations, increasing terminal capacity, and warning pilots of potentially hazardous wind shears. Gust fronts can also initiate convection, so knowing their locations can improve thunderstorm forecasts.

The objective of this study was to determine to what extent the performance of the gust front algorithm could be improved by incorporating additional radar signatures, specifically for reflectivity thin lines and/or azimuthal shears. The advantages of using a detection capability for either or both of these signatures (in addition to the algorithm's radial convergence detection) would be in increasing the percentage of the event length detected by the algorithm and detecting events that are missed because of their location relative to the radar beam. Single Doppler radar data collected in Denver in 1988 and Kansas City in 1989, representing 229 missed and 530 detected events, were used in the analysis.

Missed and detected events were considered separately in terms of strength of the event, type of signature exhibited, and improvement in percentage of total event length detected with the additional signature(s). For missed events, the data indicate that thin line detection would improve performance in Denver more than in Kansas City, whereas azimuthal shear detection would result in an equal improvement in both cities. For detected events, data indicate that thin line detection would result in detecting a greater extent of the gust front than would azimuthal shear detection in both Denver and Kansas City.

The number of missed events could be reduced by using a better convergence shear-finding technique. It is reasonable to think that such a technique might also contribute to an increase in the extent of events that are currently detected.

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