APPLICATION OF WSR-88D DOPPER DATA TO SEVERE THUNDERSTORM FORECASTING

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Abstract

Methods and procedures are introduced to "nowcast" the surface damaging winds associated with a midwestern mesoscale convective system in the United States. The three most important precursors identified to delineate which storms will produce damaging downburst winds are: 1) rapidly descending reflectivity core, 2) strong and deep convergence at mid-altitudes, and 3) a reflectivity core at higher levels. Among these, the mid-altitude radial convergence (MARC) along the forward flank of organized bowing convective systems is shown to be capable of providing lead time 10-30 minutes before the first report of severe surface wind guests. This signature can be detected at a relatively large distance from the radar site. The potential application of MARC signature to "nowcasting" of damaging winds associated with a convective system is presented.

1. Introduction

One of the most challenging aspects of severe thunderstorm forecasting is the initial onset of damaging winds. Even with the advent and more widespread use of Doppler radar, the determination as to which thunderstorms will produce damaging winds, and the location and timing of these destructive winds continues to be a major task often meet with only limited success. Traditional methods of forecasting and warning for damaging winds have been through identification of specific reflectivity characteristics which should identify thunderstorm that were generating strong downbursts. The "bulging or bowing" of the line echo was shown to be caused by the downburst (Fujita 1979). Beside the concave shaped echo configuration, Przybylinski and Gery (1983) identified three other reflectivity characteristics of the distinctive bow echo which indicated a strong probability of damaging winds. These radar characteristics were: 1) weak echo channels (WECs) or rear inflow notches (RINs) along the trailing edge; 2) a strong reflectivity gradient along the leading edge of the concave shaped echo; and 3) the maximum echo top displaced over or ahead of the strong low-level reflectivity gradient.

Recently, Eilts et al. (1996) examined Doppler radar data from over 85 downburst cases to determine the most effective radar observed precursors to use in the development of a damaging downburst prediction and detection algorithm (DDPDA) for WSR-88D. The three most important precursors identified to delineate which storm will produce damaging downburst winds versus those that will produce weak or no downbursts included: 1) a rapidly descending reflectivity core; 2) strong and deep convergence at mid-altitudes; and 3) a reflectivity core that initially begins at a higher height than most other storms. These three are similar to precursors identified and tested in previous microburst studies; however, threshold values for each of the parameters, which are more likely to be associated with damaging downbursts, have been identified. Downbursts were examined at ranges up to 150 km from the radar which produced verified damage at the surface to determine what the mid-altitude precursors to these events were. For every downburst that produced damaging winds at the surface, there was strong convergence at mid-altitudes (2-7 km) of the storm, all having convergent radial velocity difference values of > 22 m/s. Although recent studies have begun to examine mid-altitude convergence as precursors to damaging winds, they have generally focused on the prediction of damaging winds from microbursts or single downbursts, rather than damaging winds due to downburst clusters or a family of downburst clusters (Fujita and Wakimoto 1981) found in widespread convective windstorms. Only a very limited amount of studies have been conducted toward predicting widespread damaging downburst winds associated with an MCS (mesoscale convective system).

During the last few years, Przybylinski et al. (1995) and Schmocker et al. (1996) observed strong mid-altitude radial convergence (MARC) along the forward flank of organized bowing convective systems, and have begun to test this MARC signature for its potential as an indicator of the onset of damaging surface winds. The magnitudes of MARC were tested in the first occurrence of damaging winds in the 8 June 1993 squall-line event over eastern Missouri and central Illinois using the WSR-88D radar located near St. Louis. They found the strongest MARC between 3 and 7 km. The magnitudes of the radial velocity differential associated with MARC equaled or exceeded 25 m/s by as much as 25 min preceding the first occurrence of damaging winds. This velocity difference was found along a radial distance of 3 to 6 km yielding actual convergence of 4 to 8x10-3 per second.

As part of a Cooperative Program for Operational Meteorology Education and Training (COMET) Study, this research has focused on the utility of the MARC signature for forecasting the initial occurrence of damaging surface winds associated with squall lines. We begin by examining the characteristics of the MARC signature including both structural characteristics and dynamical processes which lead to strong convergence in the mid-levels of multicell bowing convective lines. A general discussion of the utility of the MARC signature to the initial onset of damaging winds is followed.

2. MARC Signature

Thus far, we have studied six MCS cases containing the MARC velocity signature. All of the events examined occurred during the warm season. Pre-convective environments for the five afternoon cases were characterized by convective available potential energy (CAPE) exceeding 3000 J/kg, while magnitudes of the 0-3 km mean vertical shear ranged from 13 to 19 m/s (moderate shear). Of these six cases investigated, four MCSs satisfied the criteria to be called a derecho. The other two cases, which evolved into bowing structures, however, failed to meet the criteria. Damaging winds were the main severe weather threat in each case. However, in three of the six cases surveyed transient tornadoes, located along the storm's forward flank, and hail reaching sizes of 3 cm were reported near vortices which satisfied mesocyclone criteria. Damaging winds would frequently occur from the leading edge of the storm's gust front and extended rearward through the region of heavy precipitation. In four of the six cases studied, we were able to capture the early stages of the MARC signature. The overall storm evolution during the early stages either exhibited a random multicell or linear multicell reflectivity pattern with two to as many as four intense convective cells identified within the complex. In the other two cases, the MCS reached the mature bowing or the early part of the dissipating stage.

Vortices, satisfying mesocyclone criteria, were observed during the early stages in five of the six cases surveyed. The majority of cases revealed that the circulation(s) initially formed near the left flank or left forward flank of the linear multicell complex. In two cases, the growth of vortices at this location may have been linked to a nearly east-west surface boundary near the northern end of the convective complex. However, two other cases showed that second and successive core circulations formed near the apex of the bow and then intensified as they traversed along the cyclonic shear side of the bowing signature. In three cases, the mesocyclone's early stage was marked by strong cyclonic shears where rotational velocities reached 25 m/s. Both transient and longer-lived tornadoes occurred near the vicinity of each strong circulation. The overall storm reflectivity and velocity pattern suggested that supercell structures were present, but for a limited period of time (e. g. < 15 min). In nearly all of the cases, the vortices diameter broadened beyond 5 km and gradually took on the characteristics of a "bookend vortex" obtaining diameters of 10 km or greater. It was also interesting to note that the MARC signature preceded the initial growth of each circulation by as much as 12 to 18 min.

During the early stages of the MCSs, one of the most consistent patterns in the velocity field is that the MARC velocity signature. As a component of the MARC velocity signature, the ribbon of outbound velocities, frequently identified along the convective system's forward flank, signified the storm's updraft center. Upwind from the broad updraft center was a region of moderate to strong intensity inbound velocities. This region marked the area of convective-scale downdrafts and the origin of the mesoscale rear inflow jet (RIJ). The MARC velocity signature frequently extended from the edge of multicell complex's right-front flank to the left frank. Intense reflectivity gradients along the storm's leading edge often coincided with the zone of strong radial convergence at middle levels. In two cases, this signature was identified as far as 220 km away from the radar, since the storm's inflow region and downdrafts were largely parallel to the radar viewing angle. At these distances, the lowest two elevation slices (0.5 and 1.5 degrees) captured the MARC velocity signature. If the storm's linear orientation was parallel to the radar viewing angle, north (south) of the radar site, we experienced difficulty in detecting the MARC signature, since associated azimuthal shears would only be sampled.

The horizontal extent of the MARC velocity signature varied from as little as 30 to as large as 95 km. In all of our samples studied, we frequently uncovered two and sometimes three local areas where velocity differentials were consistently higher than other parts of the zone of convergence. These areas of locally enhanced velocity differentials, often had an overall horizontal entent of 10 km or less, and were linked to the greatest degree of damaging surface winds. Average depth of the MARC velocity signature was 6.2 km. The greatest vertical extent was 8.5 km. The maximum intensity of the MARC velocity signature was often found between 5 and 5.5 km. Moderate to high velocity values (13-25 m/s) and steep gradients were often detected along the convergence zone. Widths of the zone of convergence varied from 2 to as large as 6 km across this region.

WSR-88D storm-relative mean velocity (SRM) data were used to compute delta-Vs and convergence along several radials for each convective system. Maximum velocity separation did not exceed 6 km for the calculation of each quantity. We frequently found that if the distance between the two velocity maxima (isodops) along a radial exceeded 6 km, the probability of severe weather would diminish. However, if the distance between the two velocity maxima along a radial was less than 6 km, and the delta-V value exceeded 25 m/s, there was an increased probability of damaging winds. We used the 6 km value as a bench mark for the components of delta-Vs. Our sample indicated that typical values of radial convergence along the zone ranged from 2.5x10-2 to 5.6x10-3 per second.

Doppler radar observations of an MCS that occurred on 28-29 June 1989 showed that the rear inflow current was not homogeneous along the length of the squall line (Klimowski 1994). Rather, the flow illustrated variability in elevation and several areas of local maxima of rear inflow. Doppler radar observations collected from our six cases also showed this degree of variability within the origins of the mesoscale rear inflow where we observed several local inbound velocity maxima along the entire length of the squall line. In many cases, two or even three local inbound velocity maxima were detected along the larger zone of mid-altitude convergence and were adjacent and upwind from local outbound velocity maxima located within the squall line's updraft current. On occasion, these local inbound velocity maxima, embedded within the lateral area of the strong inbounds, extended rearward. The close coupling of the inbound (outbound) velocity maxima reflected where radial convergence was strongest and signified the strength of the hydrostatic low within that part of the squall line. The higher the velocity differential (stronger the radial convergence), the stronger the hydrostatic low within the general zone of convergence, and the stronger the updraft (downdraft). We keyed on these areas of stronger radial convergence within the larger zone of convergence as warning signals for forecasting damaging downburst winds.

3. Discussion of Results

On 2 July 1992, a derecho developed over central

Missouri and moved eastward through east central Missouri and into parts of central and southern Illinois producing numerous reports of winds exceeding 40 m/s and several weak tornadoes along the northern leading edge of the squall line. A cluster of storms initially formed just ahead of a cold frontal boundary over west-central Missouri after 1900 UTC. A small but pronounced bowing line segment rapidly formed after 2309 near the northern end of the larger developing squall line as it moved through central Missouri. The SRM image shows convergence along the leading edge of the line in, or just ahead of, high reflectivity cores. This line of convergence extends for approximately 75 km at a height of 5 km.

Two areas of intense convergence were identified on this convergent line along the 275-278 and 280-285 degrees radials. The magnitudes of the MARC velocity signature associated with these two areas of intense mid-altitude radial convergence are plotted in time-height cross sections in Figs. 1 and 2, respectively. Both MARC velocity signatures were identified on the 0.5 and 1.5 degrees elevation slices from a height of just below 4 km up to almost 9 km. The magnitude of the northern MARC signature was 35 m/s at 2246 UTC and remains at 30 to 35 m/s just before the initial confirmed severe (25 m/s or greater) wind gust. The value of MARC increases to as high as 45 m/s during the time of wind damage between 2309 and 2332. The intensity of the southern MARC signature gradually increases prior to reports of wind damage in this area, with the highest values between 6 and 8 km from 2309 to 2321 during the times of damaging winds. Although in this case, the highest values of MARC appear to occur while damaging winds were ongoing, the identification of MARC at or above 30 to 35 m/s and/or an increase in the magnitude of MARC to this value appears to be a good predictor of damaging winds. The magnitude of the northern MARC signature was initially 35 m/s when first detected at the western edge of the SRM radar data 24 min before the first report of wind damage at 2310, while the magnitude of MARC increased to 35 m/s 18 min before the initial severe wind gusts in the southern (275-278 degrees) MARC velocity signature. A strong mesocyclone developed around 2321 as the storms evolved into a well-defined bowing line segment. The northern MARC signature was located on the southern side of this mesocyclone at 2315. This mesocyclone produced an F0 tornado at 2335 over northern Boone county. The mesocyclone gradually broadened into a bookend vortex (Weisman 1993), further strengthening the descending mesoscale RIJ and leading to prolonged wind damage across eastern Missouri and south-central Illinois. It is interesting to note that the strong (30/35 m/s) MARC signatures were identified during the initial stages of the squall line evolution, before the development of any well-defined bow echoes, or strong vortices. This kind of velocity evolution has been observed with other MCS cases in our study.

4. Summary and Conclusions

These two cases plus the four other squall-line cases so far examined appear to show a good correlation between values of MARC of at least 25 to 30 m/s to successive damaging surface wind gusts. It appears that the width of the MARC signature should be no more than 6 km, or values of actual convergence will be too small even with a velocity differential of > 25 m/s. It also appears that this signature is usually identified from the time when the storm complex develops into a linear multicell structure through the evolving stage of the bow echo. This velocity signature is less likely to be detected, or at least detected at a weaker magnitude, in the mature or dissipating stages of a bowing convective line.

Two of the major advantages of using the MARC signature as a precursor to damaging winds include: 1) potentially longer lead times (10-30 min before the first report of severe wind gusts), and 2) the relatively large distance from the radar which one can detect this signature. Also, the magnitude of MARC does not fluctuate with differing air masses and seasons. One major disadvantage of using this signature occurs when mid-level convergence is orthogonal to the radar beam, and velocities and convergence values are greatly underestimated. This is a typical disadvantage of single Doppler analyses of storm motions. Although many more cases will need to be studied in the future, these initial results are promising and have shown that detection of this MARC velocity signature in the severe weather warning process may lead to more accurate and timely warnings of damaging winds from organized convective systems.

5. Acknowledgments

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6. References

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MID-ALTITUDE CONVERGENCE

JULY 2, 1992

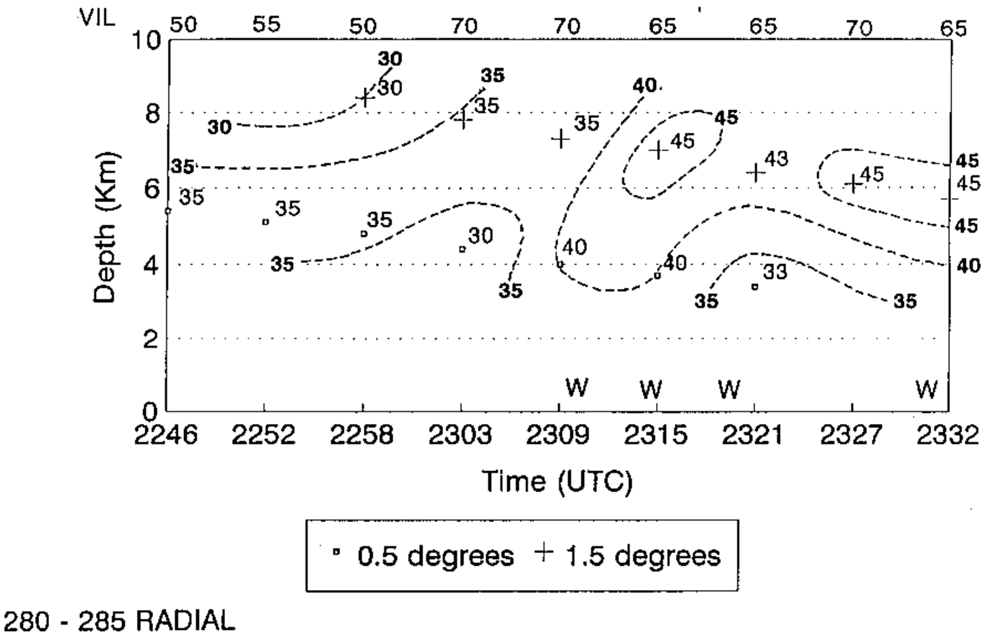

Fig. 1. Time-height cross section of MARC, in units of m/s, at the 280-285 degrees radials. W denotes wind damage.

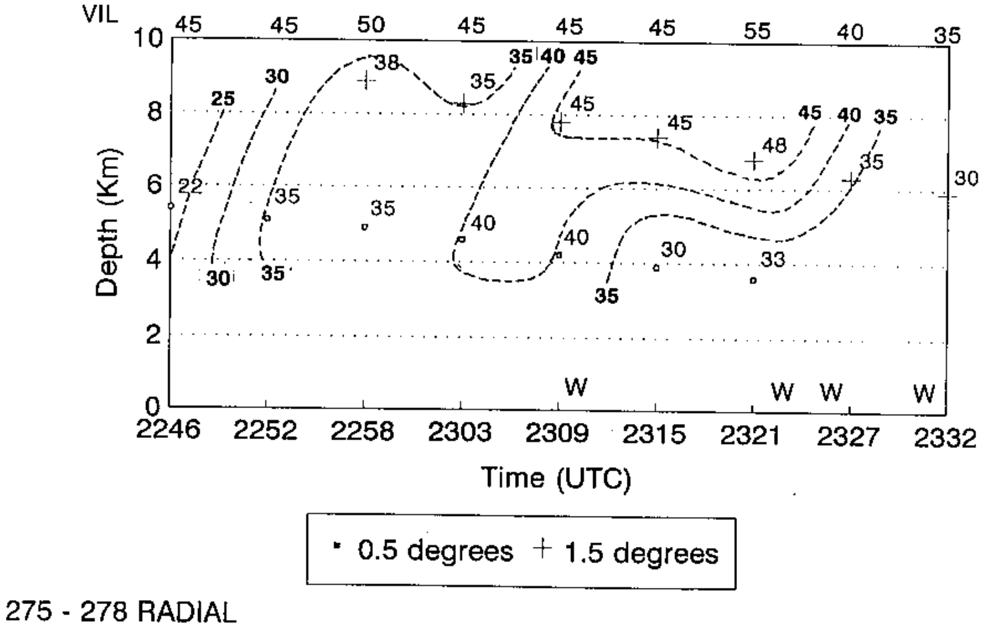

Fig. 2. Time-height cross section of MARC, in units of m/s, at the 275-278 degrees radials. W denotes wind damage.