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Investigation of Derecho Storms in Oklahoma and the Causes of Highest Surface Wind Speeds

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1. Introduction

Two mesoscale convective system (MCS) derecho-producing events were examined for this study. The derecho events of May 27-28, 2001 and June 16-17, 2005 affected large portions of Oklahoma during the evening and overnight hours. The May 27-28, 2001 event produced over 100 severe winds during a six-hour period, while the June 16-17, 2005 event produced over 30 severe winds during a six-hour period. Most of the winds were in the 27-31m/s range. However, there were gusts in the upper 30s to 44m/s. Fig. 1 shows these wind swaths.

Johns and Hirt (1987) have developed a checklist to aid operational forecasters in forecasting derecho events. The purpose of this study however is to identify the cause of the severe wind gusts and to suggest a methodology to aid forecasters while a derecho event is ongoing.

2. Background

Derecho-producing MCSs affect areas from the Great Plains to the Midwest and into the Ohio River Valley from early spring into late fall. The term derecho, as noted by Johns and Hirt (1987), is defined as any family of downburst clusters produced by an extratropical MCS.

As noted by Coniglio et al. (2004), these severe straight-line winds can be caused by mesohighs, gust fronts, or downbursts. Johns and Hirt (1987) show that the highest surface wind gusts are associated with the apex of the bow echo feature of the convective line. Atkins et al. (2005) and Coniglio et al. (2004) also propose an alternative idea as to the cause of these damaging winds.

In a 2003 BAMEX case study by Atkins et al. (2005), mesovortices along the

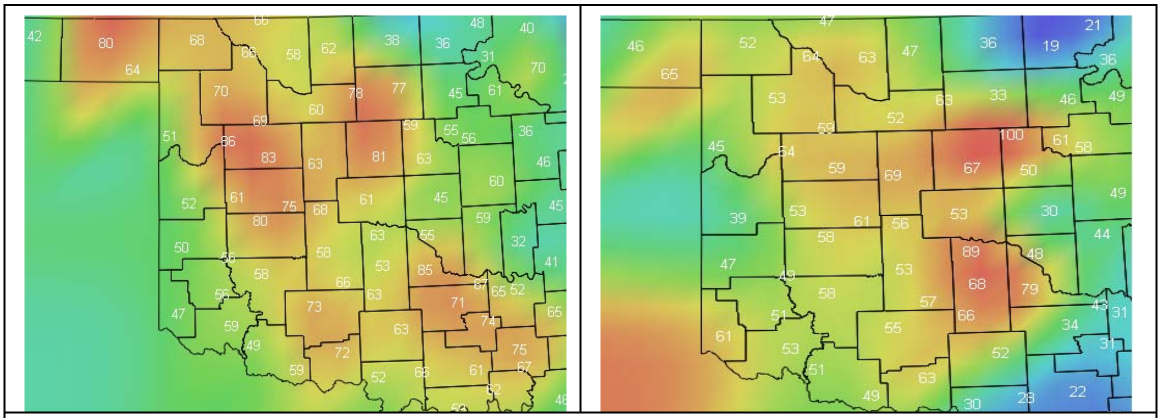

Fig. 1. The graphic on the left shows the maximum daily wind gusts for each Oklahoma Mesonet site on May 27, 2001. The graphic on the right shows the maximum daily wind gusts for each Oklahoma Mesonet site on June 16, 2005.

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leading edge were found to have produced some of the highest surface wind speeds during the derecho event. It was also stated by Atkins et al. (2005) and others (Miller and Johns 2000) before them that damaging winds may also occur with embedded supercells within the convective line. These methods for generating severe surface wind gusts will be discussed in greater detail in section seven. Sections three and four will elaborate on the criteria for classifying a system as a derecho and the mechanisms for creating severe gusts. Section five will provide the analysis methods and results and section six presents the summary and conclusion.

3. Criteria

Johns and Hirt (1987) outlined some of the most detailed criteria for classifying a derecho event. These six criteria are as follows:

1. There must be a concentrated area of reports consisting of convectively induced wind damage and/or convective wind gusts greater than 26 m/s. This area must have a major axis length of at least 400km.
2. The severe gust reports must show a pattern of chronological progression.
3. Within the area there must be at least three reports, separated by 64km or more, of either F1 (33-50m/s) damage and/or convective gusts of 33m/s or greater.
4. There can be no more than 3 hours between successive severe wind gusts.
5. The associated convectively-induced system must have temporal and spatial continuity. However, movement of radar echoes associated with the system need not be continuous.
6. Multiple swaths of wind damage and gusts must be a part of the same mesoscale convective system.

Evans and Doswell (2001) go on to refine the criteria by adding that the minor axis have a width of at least 74km and the convective system is not associated with a tropical storm or hurricane. Coniglio et al. (2004) also used radar representation to classify derecho events by saying that they must show a linear or bow echo structure. These criteria were used for the purposes of this study.

4. Mechanisms for producing severe gusts

a. Rear Inflow Jet

Many studies (Atkins et al. 2005; Bentley and Cooper 1997; Johns and Hirt 1987) have found that there is a strong correlation between damaging wind gusts and the apex of the bow echo. Fujita (1979) proposed that the rear inflow jet (RIJ) was the reason for this. The RIJ is caused by warm air aloft in the ascending front to rear flow of the line and the evaporative cooling, melting precipitation and downward transport of cooled air creating thunderstorm downdrafts and a cold pool at the surface (Bentley and Cooper, 1997). This results in a pressure and buoyancy perturbation on the backside of the convective line that produces positive (clockwise) curvature vorticity aloft and negative (counter-clockwise) curvature vorticity near the surface. This vorticity couplet in turn results in the RIJ. If the buoyancy gradient in the cold pool is stronger than the buoyancy gradient in the warm air aloft, the RIJ will descend towards the ground along the leading edge of the

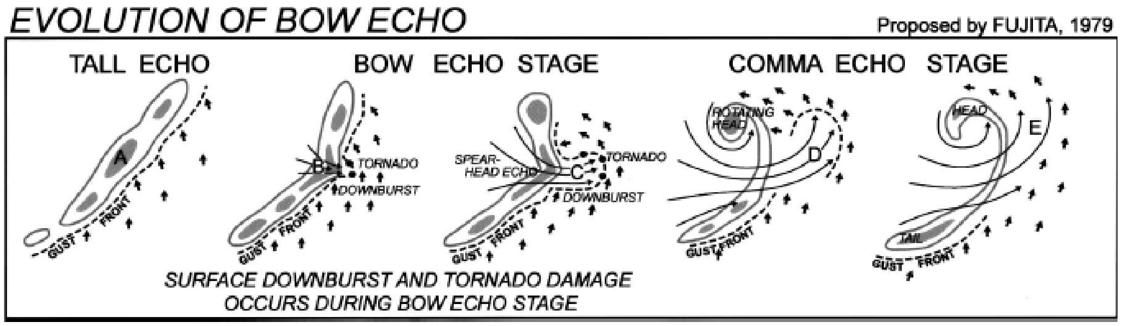


Fig. 2. This figure, from Atkins et al. (2005) and first proposed by Fujita (1979), shows the evolution of a bow echo. Notice in B and C that the rear inflow jet causes the line to bow.

convective line (Atkins et al. 2005). The RIJ brings drier air into the convection, hence enhancing the downdrafts, which causes higher surface wind gusts along the apex. Therefore, the RIJ is responsible for not only the bowed structure that can occur but also for damaging surface wind speeds. Fig. 2 shows the evolution of a bow echo and how the RIJ shapes the bowed features on radar.

b. Embedded Supercells

The RIJ is not the only mechanism for creating severe wind gusts during bow echo storms. Conditions during MCS events are comparable to those that would produce supercells. Therefore, embedded supercells within the convective line can also be responsible for damaging surface winds. Microbursts from embedded supercells can cause damaging severe wind gusts anywhere along the line they may form. Embedded supercell mesovortices can also cause damaging winds and even tornadoes (Johns and Hirt 1987; Bentley and Cooper 1997; Atkins et al. 2005).

c. Mesovortices

A third possible mechanism for the generation of severe surface wind speeds is mesovortices along the leading edge of the convective line. Atkins et al. (2005) suggest that straight-line winds are produced by the tight horizontal pressure gradient across these mesovortices.

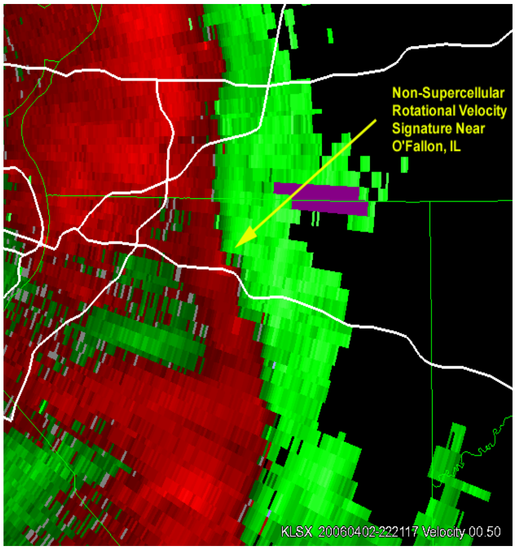


Fig. 3. St. Louis National Weather Service WSR-88D radar shows the velocity signature of a mesovortex. This mesovortex produced an F2 tornado in the heavily populated area of Fairview Heights and O'Fallon Illinois.

A recent event shows that mesovortices occurred on April 2, 2006, as a quasi-linear convective system (QLCS) moved through the St. Louis, Missouri metro area (National Weather Service 2006). Ten tornadoes occurred in this event; of these ten, six were caused by leading edge mesovortices and four by embedded supercells. These mesovortex tornadoes caused anywhere from F0 to F2 winds. Some of the worst damage was caused by leading edge mesovortices, which spawned two F2 tornadoes. Fig. 3 shows an example of the velocity signature of one of the leading edge mesovortices that caused F2 damage. As Fig. 3 shows, the mesovortices are very small features. Atkins et al. (2005) notes that mesovortices are usually on the order of 1 to 10 km. This can make detection difficult for forecasters and therefore reduce warning time, which increases the danger of these severe wind producers. This particular mesovortex and associated tornado killed one person and caused numerous injuries throughout the area (National Weather Service 2006).

5. Analysis and Results

a. Analysis Method

As has been discussed, strong winds associated with derechos are likely to come from four places: the gust front/outflow boundary, the locations surrounding the apex of the bow echo, embedded supercells, and mesovortices. However, the majority of wind damage occurs in the downbursts and mesovortices (Atkins, et al. 2005). Two derecho cases in Oklahoma, May 27-28, 2001; and June 16-17, 2005, were selected to test these findings. These cases were selected for investigative work on wind speeds in relation to structure of the storms on radar, as well as the involvement of equivalent potential temperature gradients. It should be noted that only two cases were chosen, as both cases possessed similar behavioral patterns. It was decided that the upper-air observations would be neglected for the purposes of this study because the events did not occur close to the times of upper air observations in the region of interest; thus there was insufficient data to construct storm-environment upper air analyses. Therefore, the focus was mainly on surface observations and radar data.

In both cases, surface maximum wind gust data were collected from the Oklahoma Climatological Survey (OCS) Mesonetwork and plotted using the OCS software WeatherScope. Radar data from the Vance Air Force Base, Tulsa, Oklahoma City, and Frederick National Weather Service WSR-88D radars in Oklahoma were used. Surface equivalent potential temperature also was contoured. Each variable was overlaid on one another to create a composite map. The data were then processed at five-minute intervals. These intervals were chosen due to the way the Mesonet records wind gusts and also because radar updates approximately every five minutes. The maximum wind gust is the highest three-second wind speed in a five minute period (Brock et al. 1995). Each gust of 25m/s or higher was considered from any Mesonet site affected, as this is the criterion for severe winds. Radar reflectivity and base velocity data were analyzed to determine the structure of the convective line at the time of the severe wind observation. For each observation, it was determined if the wind gust was the result of an embedded supercell, the result of the apex or associated gust front, or caused by a leading edge mesovortex.

b. Results

The results are similar to what is expected of a derecho event. Most of the severe wind gusts occurred within the apex of the bow echo or from embedded supercell downbursts. The May 27-28, 2001 event recorded 128 severe winds with 40% of the gusts occurring in the apex region, 34% supercell downburst, 20% from the gust front and 6% attributed to a mesovortex; as is show in Table 1. The June 16-17, 2005 event included 29 severe gusts with 31% associated with the apex, 17% embedded supercell downbursts, 31% occurring along the gust front, and 21% due to mesovortices; which is also shown in Table 1. Table 2 discusses the characteristics of the theta-e field and will be discussed later. Fig. 4 shows examples of the locations that produced damaging wind gust from the two cases studied. Clearly, the apex and its associated downbursts are the most likely area to expect damaging surface wind speeds. However, forecasters should not neglect the gust front and the leading edge of the line, as these events clearly produce damaging winds from numerous sources.

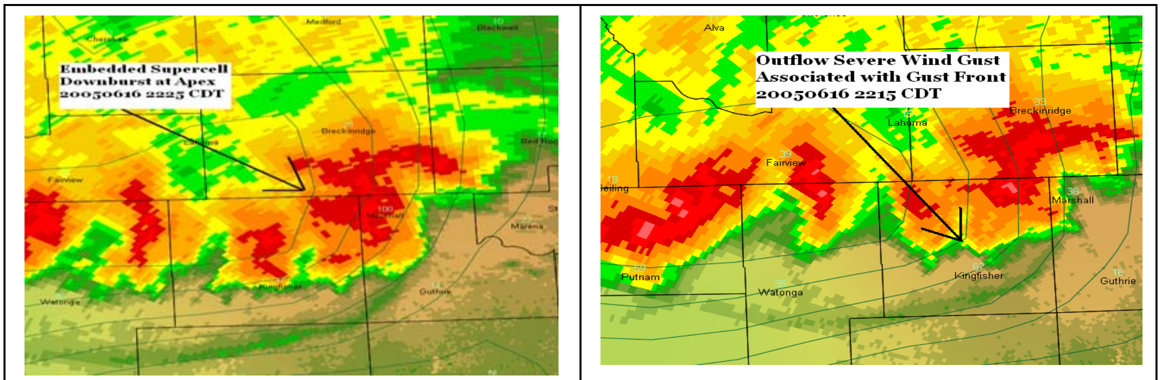
The severe gusts also occurred along several different types of theta-e gradients. These were classified as having weak, tight, or very tight gradients as well as being linear, slightly bowed, or highly bowed. The theta-e gradient was considered weak if the gradient was 20 K/100km to 29 K/100km, tight if 30 K/100km to 39 K/100km and very tight if 40K/100km or greater. Fig. 5 shows examples of the linear, slightly bowed and highly bowed theta-e gradients and Table 2 shows the frequency that these structures occurred. As shown in Table 2, the May 27-28, 2001 case had a weak gradient 10% of the time, a tight gradient 87% of the time and very tight 3% of the time. The gradient was linear 54% of the time, slightly bowed 38% of the time and highly bowed 8% of the time. Table 2 also shows the June 16-17, 2005 case had a weak theta-e gradient 35% of the time, a tight gradient 41% of the time, and a very tight gradient 24% of the time. The gradient was linear 28% of the time, slightly bowed 38% of

Table 1. Location of severe gusts.

Location	**May 27-28, 2001**	**June 16-17, 2005**
Apex	40%	31%
Supercell	34%	17%
Gust Front	20%	31%
Mesovortex	6%	21%

Table 2. Theta-e characteristics.

Theta-e Gradient	**May 27-28, 2001**	**June 16-17, 2005**
Weak	10%	35%
Tight	87%	41%
Very tight	3%	24%
Theta-e shape	**May 27-28, 2001**	**June 16-17, 2005**
Linear	54%	28%
Slightly bowed	38%	38%
Highly bowed	8%	24%



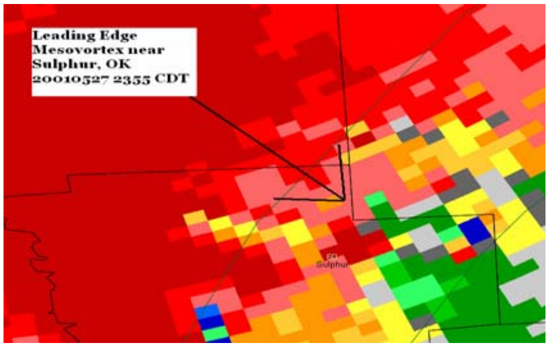


Fig. 4. The radar reflectivity image in the upper left shows a location where a severe wind gust occurred with the gust front associated with the bow echo. The upper right reflectivity image shows an embedded supercell that was responsible for a downburst that produced a severe wind gust. The bottom left image shows the base velocity along the leading edge of the bow echo and an associated mesovortex that produced a severe wind gust.

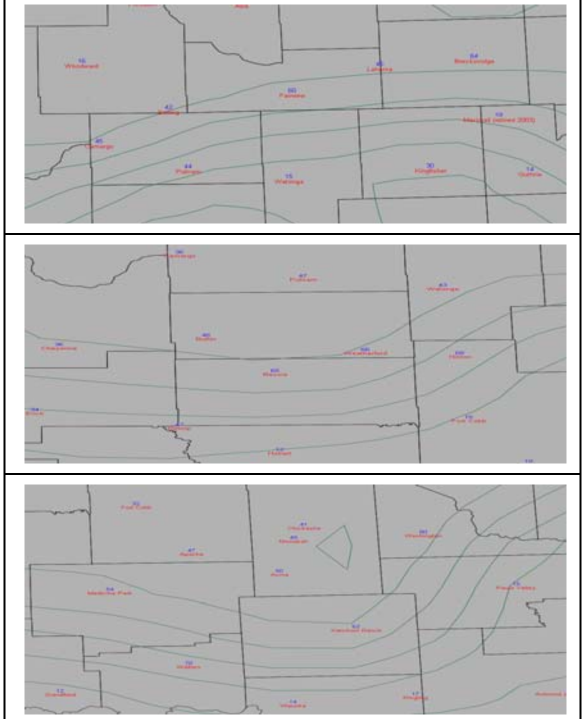


Fig. 5. The theta-e gradients were classified as linear (top), slightly bowed (middle) or highly

the time, and highly bowed 34% of the time. Of the severe gusts that occurred in both events, there were extreme gusts in all forms of the theta-e gradient.

c. Comparisons

While the two researched cases were similar with respect to severe wind gusts occurring at or near the apex, many differences were noted between severe winds found in other locations. For example, from the evidence found for the June 2005 case, it appeared that a tight, slightly bowed gradient favored apex, gust front, and mesovortex severe wind gusts. Embedded supercells appeared to favor a tight, linear theta-e gradient for the May 2001 case. It would seem that a tight theta-e gradient may concentrate severe winds near the apex, as was the case in the May 2001 event. A weaker gradient environment allowed severe gusts to be dispersed more evenly throughout the structures of the convective line due to the fact that this allows all mechanisms to be equally dominant. A bowed gradient in the theta-e field may be related to the strength of the cold pool, which also may allow severe wind gusts to be more evenly distributed throughout the system. The bowed structure of the theta-e field and its possible relationship with the cold pool may have implications on mesovortex formation, but more research is needed to make this conclusion.

6. Summary and Conclusions

In summary, the general hypothesis behind the research was confirmed, in that the highest wind speeds are typically collocated with the apex or embedded supercell regions of the derecho cases studied. The majority of severe winds during these events happened in these locations. A smaller percentage of severe wind gusts were located with the gust front or mesovortices. As a result, it can be confidently stated that a large percentage of severe wind gusts during derechos can be associated with either the apex or an embedded supercell downburst. Although high wind gusts can often be seen among other structures, the probability of occurrence is much smaller, but these locations should not be neglected. The CASA project, which is currently taking place in parts of Central and Southwestern Oklahoma, may prove to be useful in better detecting mesovortices due to closely spaced x-band radars that provide better spatial and temporal resolution than the current NWS WSR-88D s-band radars.

It also was found that bowing structures in the theta-e environment could have an impact on the location of severe wind gusts. However, the research showed that there was much less of a correlation between theta-e structure and the highest wind gusts for the June 2005 event, as high wind gusts did not appear to favor primarily a linear or strongly bowed theta-e environment. It appeared that high wind gusts occurred in every form of the theta-e environment. Therefore, more research is needed to see just what effects the theta-e gradient has on the mechanisms for creating severe wind gusts.

In the future, these results could have implications in the forecasting techniques of derechos. Although the apex is generally considered the most dangerous location for severe wind gusts, these results have shown that the gust front and mesovortices are not to be neglected. A forecaster should look at the data available to make the best decision possible for issuing warnings, in addition to short-term forecasts, in order to ensure the safety of people who may be in the path of the severe winds of a derecho.

Many questions can be raised from the subject of derecho research. Patterns in radar structure or surface data could be found relating environmental conditions to the most likely mechanism to create severe winds. Tornadoes within derechos or long-term wind events could be detected or even predicted from situations where storm structure was otherwise normally difficult to distinguish. More research can be conducted on the environmental theta-e gradient and how its characteristics affect mechanisms for creating high winds. In addition, finding the conditions responsible for the generation of mesovortices would be valuable for forecasters by adding to the derecho forecasting checklist as suggested by Johns and Hirt (1987).

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