Conditions Associated With Derechos Occurring in Dry Boundary Layer Environments

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Abstract

The purpose of this study is to determine environmental conditions that are most favorable for the development of widespread convectively induced windstorms that occur within relatively dry boundary layer conditions. Events such as this are difficult to forecast, as are most organized convective windstorms occur within a moist boundary layer. In this study, a dataset composed of 8 dry boundary layer organized wind events that occurred during the months of March, April, May, July and November for a 12-year period of 1989-2001.

1. **Introduction:**

East of the Rockies during the late spring and summer months, organized mesoscale convective systems (MCS) develop and create widespread damage across large areas. Also described as a bow echo, it is identified as a type of convective storm structure linked with damaging winds or downburst (Johns 1993, p.294).

The term "bow echo" was introduced by Theodore Fujita as a representation of the evolution of downburst winds creating a bow look in the line echo (Przybylinski 203). One distinct feature that the bow echo possesses is its long, narrow swaths of damaging straight-line winds. A bow echo's evolution has three stages (tall echo, bow echo, and comma echo) (Przybylinski 203).

Numerous meteorological conditions correlated with bow echo development (Johns 1993, p.294). In a study performed by Johns and Hirt (1987) revealed that vigorous bow echo development associated with convectively induced widespread damaging winds (derechoes) typically occur within strong, migrating low pressure systems or with stagnant weather patterns displaying relatively weak synoptic-scale features (Johns 1993, p.294). There are two basic synoptic patterns associated with bow echo/derecho events; the warm season pattern and the dynamic pattern.

The warm season pattern derecho usually occurs during the late spring and summer and is associated with a singular swath of wind damage due to an isolated bow echo or a short squall line with multiple bow echoes (Johns and Hirt 1987, p.33). This derecho moves along a quasi-stationary low-level thermal boundary, which is nearly parallel to the mean tropospheric flow. The mid- and upper-level airflow is usually westerly to northwesterly and may possibly be anticyclonic. Midlevel wind speeds tend to be rather strong for the late spring and summer (Johns 1993, p.294). The thermodynamic conditions involved with the warm season pattern suggest that the strongest and most long-lived bow echo systems occur when there is moderate to strong vertical wind shear above ground in the lowest 2.5 km, with constant winds above in the middle layers of the atmosphere (Johns 1993, p.294).

The dynamic pattern derecho has been known to occur during all seasons while it is associated with a series of swaths and a strong, migrating low-pressure system. Usually, a widespread squall line will develop along a cold front and the derecho activity would be embedded in this line (Johns 1993, p.297). Usually the midlevel winds that accompany the dynamic pattern bow echo are usually stronger than that of the warm season pattern derecho, most notably in the late fall into the early spring (Johns 1993, p.297). The thermodynamics associated with the dynamic pattern vary considerably; a general feature that the pattern possesses is a layer of dry, potentially cold air in the downdraft entrainment layer (Johns 1993, p.297).

Recent efforts have drastically improved operational meteorologist's ability to recognize and anticipate the development of the warm season bow echoes. The main focus has always been on derechos that develop and move through very moist boundary layers with strong instability. Problems still remain for forecasting derechos that form in relatively dry boundary layers. In this study, 8 cases are examined that show convectively induced wind events that formed in a relatively dry boundary layer with low instability. Although these types of events occur less frequent than those in a moist boundary layer, they cause a considerable amount of wind damage to a large area and could result in fatalities and injuries.

Derechos seem to account for many of the fatalities and much of the damage due to convectively induced nontornadic winds (Johns and Hirt 1987 p.33), but documentation on bow echoes of this nature are lacking due to the difficulty in forecasting these types of events. The purpose of this study is to take a closer look at the convective wind events (derechos) that formed in relatively dry boundary layers and develop a composite of the synoptic patterns associated with the 8 cases. These composites hopefully will provide meteorologist with the tools to better forecast these events.

2. Synoptics of Bow echo Cases

According to a study performed by Robert H. Johns (1993), the warm season synoptic pattern for a derecho is a quasi-stationary low level thermal boundary oriented nearly parallel to the mean tropospheric flow. The upper flow is tropically northwesterly and wind speeds average 35 to 40 kt at the 500 mb level (Johns 295). The air along the thermal boundary in typically extremely unstable, this is usually the result of very high values of low-level moisture located in the convergence zone near the boundary (Johns 295). Long-lived warm season pattern derechos display an average maximum CAPE value of 4500 J/kg. This strong instability gives the derecho event the energy its needs to remain strong in conditions of weak forcing (Johns 296). Typically moisture values in the convergence zone are greater than in the surrounding area (Johns 296). It's not unusual for a tornado to be associated with derecho during the warm season pattern. The tornado development is typically shear induced rather than associated with a mesocyclone (Johns 297).

The synoptic conditions associated with the 8 cases that were studied involved a linear forcing mechanism (cold front, trough…) to initiate the storm, deep, dry, well-mixed layers that were surmounted by a shallow layer of moisture, deep layer of moderate to strong unidirectional winds, unusually low dew points, low CAPE values and low precipitation values, moving along a strong, low-pressure system. The CAPE values that were recorded for this study would lead a forecaster to believe that there would not be enough instability for any convection to occur. The mean values for most unstable (mu) CAPE were 332 J/kg. These events are also capable of producing tornadoes. There were a total of four tornadoes (all F0) that developed and contributed to the wind damage.

4. **Methodology**

A great deal of this study involved hand analysis of upper air and surface charts for the times before, after and during each wind event. The analyses included plotting height contours, isotachs, and isotherms on the upper air maps, and isobars and isotherms on the surface maps. Composite charts were created from surface and upper-air maps, using a 6 x 6 grid mesh with approximately 300 miles of spacing. The center point of the grid symbolizes the midpoint of the storm or where the most intense wind damage had taken place. The heights, temperatures and dew points were recorded for each point on the grid (using the 850 mb, 700 mb, and 500 mb upper air maps along with the surface map) to composite the features of the environment as the event took place. These analyses were then examined to determine the leading factors that contributed to the development of a bow echo within a relatively dry boundary layer environment.

Mean values were recorded for the thermodynamic and kinematic parameters from the soundings of each case. These parameters include; convective available potential energy (CAPE), lifting condensation level (LCL), level of free convection (LFC), equilibrium level (EL), precipitable water, mean mixing ratio (Mean Q), 700 – 500 lapse rate, the 850 –500 lapse rate, surface to 6 km mean wind (sfc – 6 km), sfc – 1 km shear and sfc – 6 km shear.

5. Case Breakdown

The cases that were chosen for this study were mainly from the Midwestern and the East/Northeastern states (7of the 8 cases). In this section, each event is explained in terms of the beginning and ending times, center point of the event, tornado reports, hail reports, wind damage reports, injuries, fatalities, states affected and maximum wind speed.

5.1 November 21, 1989

This event was centered near Williamsport, Pennsylvania between the time of 2300-0300 UTC and the 0000 UTC (19 Nov 1989) time was used for the composite chart analyses. The 850, 700 and 500 mb upper air charts at 0000 UTC show a low pressure system over the top of the Northeast coast with strong upper level winds at the 250 mb chart in the range of 90 to 110 knots. The surface grid shows that the temperatures in and surrounding the event range from 23 to 64 degrees Fahrenheit. This lager temperature contrast is due largely in part to the location of the event. Dew points range from 7 to 40 degrees Fahrenheit. This event produced 2 tornadoes (F0 and F2), with 147 reports of wind damage, and .75in hail. Three states were affected during this event (Massachusetts, New York, and Pennsylvania). There were no fatalities and a total of 6 injuries. The strongest winds that were reported reached 82 knots.

5.2 April 19, 1994

This event was centered over Milwaukee, Wisconsin between the time of 2300-0300 UTC and the 0000 UTC time was use for composite chart analyses. The 850, 700 and 500 mb upper air charts at 0000 UTC show a low pressure system over Wisconsin extending down into Missouri. The 250 mb upper chart shows the winds in the upper level around the event range from 60 to 70 knots. The surface grid chart shows that the temperatures surrounding the event ranged from 55 to 70 degrees Fahrenheit. The dew points surrounding the event range from 25 to 50 degrees Fahrenheit. This was a relatively light case with no tornado or hail reports and only 14 wind damage reports. There were two states affected by this event (Michigan and Wisconsin). There were 6 injuries and no fatalities, with the strongest winds reaching 82 knots.

5.3 May 31, 1994

This event was not found in the typical location of where bow echo events would normally take place (east of the Rocky Mountains). This event was centered over Salt Lake City, Utah between the time1800-2100 UTC and 1800 UTC was used for the composite chart analyses. The 850, 700 and 500 mb upper air charts at 1200 UTC show a ridge moving over Colorado, Utah and Wyoming. The 250 mb upper air chart shows that the wind speeds in the upper levels were in the range of 50 to 75 knots. The surface grid at 1800 UTC shows that the temperatures range from 50 to 75 degrees Fahrenheit and the surface dew points range from 40 to 55 degrees Fahrenheit. There was one report of a tornado (F0) and one hail report (.75in) with a total of 16 wind damage reports. There were a total of three states affected by this event (Colorado, Utah, and Wyoming). There were15 injuries and no fatalities, with the strongest winds reaching 91 knots.

5.4 November 21, 1994

This event was centered over St. Louis, MO between the time of 0300-0900 UTC and 0600 UTC was used for the composite chart analyses. The 850, 700 and 500 mb charts at 0000 UTC show a low pressure system centered over Kansas and Nebraska moving toward Missouri. At 1200 UTC the low-pressure system was directly over Missouri. The 250 mb chart shows the upper level winds ranging from 70 to 100 knots over Missouri. The surface grid shows that temperature surrounding the event at 0600 UTC ranged from 45 to 55 degrees There were no reports of tornadoes or hail. There were 21 reports of wind damage across three states (Illinois, Kentucky, and Missouri). There were 8 injuries and no fatalities, with the strongest winds reaching 91 knots.

5.5 April 5, 1995

This event was centered over Kingston, New York between the time of 1200-2100 UTC and 1500 UTC was used for the composite chart analyses. The 850, 700 and 500 mb charts at 1200 UTC show a low pressure system over the northern East coast. The 250 mb chart shows the upper level winds ranging from 70 to 100 knots. There were no reports of tornadoes and 2 hail reports. There were 98 wind damage reports across 6 states (Connecticut, Delaware, Massachusetts, New York, Pennsylvania, and Rhode Island). There were 2 injuries with no fatalities, with the strongest winds reaching 91 knots.

5.6 April 5, 1997

This event was centered over Clinton, Iowa between the times of 1500-0300 UTC and the 2100 UTC time was used for the composite chart analyses. The 850, 700 and mb charts at 1200 UTC show a low pressure system approaching the Midwest from the West. The 250 mb chart shows upper level wind speeds ranging from 85 to 100 knots. There was 1 report of a tornado (F0) that touched down in Quincy, Illinois. There was 1 report of hail damage in Oshkosh, Wisconsin while there were 147 reports of widespread wind damage that affected 7 states (Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, and Wisconsin). There was only 1 injury and no fatalities, with the strongest winds reaching 78 knots.

5.7 July 5, 1997

This event was centered over Asheville, North Carolina between the times of 1900 (July 4) -0600 UTC and the 0000 UTC (July 5, 1997) was used for composite chart analyses. The 850, 700 and 500 mb chart at 0000 UTC shows a trough moving through the East coast. The 250 mb upper level show winds ranging from 40 to 75 knots. There were no reports of tornadoes or hail damage. There were 124 reports of wind damage that affected 5 states (Georgia, North Carolina, South Carolina, Tennessee, Virginia). There were a total of 22 injuries and no fatalities, with the strongest winds reaching 69 knots.

5.8 March 14, 2001

This event was centered over Rockville, Maryland between the times of 0000-0300 UTC and the 0000 UTC was used for composite chart analyses. The 850, 700, and 500 mb charts at 0000 UTC show a low pressure system over the East coast. The 250 mb chart shows winds speed ranging from 100 to 130 knots. There were no reports of tornado or hail damage. There were 51 reports of wind damage that affected 3 states (Maryland, Pennsylvania, and Virginia). There were no fatalities or injuries reported, with the strongest winds reaching 91 knots.

Results

The composite surface map shows that each of the eight wind events had composite dew points generally that ranged from 32 degrees Fahrenheit to 59 degrees Fahrenheit. The average most unstable CAPE (MU CAPE) was 332 J/kg. The average LCL height was 789 mb, while the LFC was 751 mb. The average percipitable water was 0.62 inches and the 500-700 mb lapse rate were 16 C / 6.9 C/km. The mean surface to 6 km wind was 219 / 40 kt, while the 1 km and 6 km shear were 7 kt and 61 kt respectively.

Conclusion

While only eight events were examined in this study, the information that was collected should be viewed as preliminary but also as a useful first step in learning to recognizing these rare types of convective windstorms. It has been shown that the widespread convectively induced windstorms that form within dry boundary layers are associated with unstable upper level synoptic patterns, low CAPE and moisture values moving along low-pressure systems. Hopefully the data collected can be used for future studies and as an aid to help operational meteorologist recognize and determine where the relative risk for these types of bow echo events will occur.

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