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MESOSCALE VORTICES AND MESOCYCLONES AS PRECURSORS TO DERECHOS

William R. Cotton*, Ray McAnelly and Cory Wolff
Colorado State University, Ft. Collins, Colorado

1. INTRODUCTION

In a three dimensional simulation of an observed derecho-producing squall line, Schmidt (1991) diagnosed an upward-directed pressure gradient force (PGF), due to an induced low formed by an elevated rotating updraft or a mesocyclone. This serves to lift stable air up from the surface, whereupon it becomes negatively buoyant. Once the stable air passes through the region of uplift, it will descend rapidly back towards the surface with melting and evaporation of precipitation enhancing its negative buoyancy. This "up-down" downdraft (Knupp 1987) is thought to be a major component of nocturnal derechos where there is an abundance of stable air beneath the system. Bernardet and Cotton (1998) simulated a long-lived derecho-producing MCS in both its daytime and nighttime phases. The source of the downdraft air was ahead of the storm in both phases, but during the day it came from the surface air lifted by the gust front and upward-directed PGF enhanced by a mesocyclone, while at night it was from the surface stable layer and was lifted solely by the mesocyclone-driven upward-directed PGF. The rear-inflow-jet and its manifestation of a bow-echo in this concept is not directly involved in downdraft formation, but it responds to the elevated low pressure that develops in the storm. The same low pressure region that drives the rear-inflow-jet forms the vertical PGF, which drives the up-down downdraft circulation.

In this paper we examine observational evidence supporting the role of mesoscale vortices and mesocyclones in derecho formation.

2. METHODOLOGY

Five derecho events were chosen for this study. Each occurred during the warm-season and met the six criteria outlined by Johns and Hirt (1987) to be classified as a derecho. They were all located in the north-central U.S., near the axis of maximum derecho frequency documented by Johns and Hirt (1987). The events were chosen by examining the convective wind reports in Storm Data. When large numbers of wind reports were found in the same general area and on the same day they were scrutinized to make sure that they met the first four criteria. If so, then radar mosaic charts were consulted for the last two to verify that the wind reports emanated from a temporally and spatially continuous MCS. After this, the time and intensity of each report was plotted on state maps to get a better idea of the evolution of the systems. A synoptic analysis was done using NWS DIFAX charts, archived soundings, and RUC analysis data. The RUC data were converted to binary format and displayed using the Grid Analysis and Display System (GrADS). This allowed for better time resolution (every 3h) of large scale features as well as for soundings to be created for points along the path of the derechos. We performed case study analysis of each event, including an overview and analyses of the prestorm environment, storm evolution, and demise. The radar mosaic images were produced with GrADS using data from the Global Hydrology Resource Center.

3. CASE STUDIES

The selected cases were:

a) Case 1: June25-26, 1999
b) Case 2: July 22-23, 1999
c) Case 3: July 30-31, 1999
d) Case 4: May 29-30, 2000
e) Case 5: June 25-26, 2000

4. RESULTS

Table 1 (on last page) summarizes some of the important synoptic features in both the prestorm environment and during storm evolution that emerged during this study for the five cases.

The derechos all formed on and moved along a surface boundary. This acted as a convergence zone for the warm air and moisture on which the systems fed. There was no shortage of low level moisture either. Dewpoints were quite high for all except Case 4. None of the cases occurred ahead of a high amplitude upper level trough that could be classified as a strongly forced case (Evans and Doswell 2001).

The amounts of instability and shear have been shown to be important to derecho evolution. Table 2 shows the averaged CAPE and 0-6 km shear values for all cases at initiation and near the derecho midpoint. On the average the derechos encountered the most unstable air near their midpoints, which is expected (Johns and Hirt 1987).

*Corresponding author address: Prof. W.R. Cotton, Colorado State Univ., Dept. of Atmospheric Science, Ft. Collins, CO 80523-1371; FAX: 970-491-8449; e-mail - cotton@atmos.colostate.edu

5. RADAR ANALYSIS

WSR-88D radar data from National Weather Service (NWS) radars were obtained from the National Climatic Data Center (NCDC) and viewed using the WSR-88D Algorithm Testing and Display System (WATADS), available from the National Severe Storms Laboratory (NSSL). Features such as bow echoes, rear inflow notches (RINs), and mesocyclones were identified. The mesocyclone detection algorithm (MDA) allows the tracking of circulation areas with time by plotting a circle to denote its location along with lines marking its path in previous volume scans. This was useful to determine the location of the wind reports in relation to circulations. The algorithm also provided a table for each detected circulation in the volume scan that calculated things such as azimuth and range, strength rank, mesocyclone strength index (MSI), base height, depth, low altitude diameter, low altitude rotational velocity, maximum rotational velocity, maximum shear, maximum gate-to-gate velocity difference, and the ground relative speed and direction of the circulation movement. The strength rank parameter is based on parameters such as rotational velocity, shear, and maximum gate-to-gate velocity difference (WATADS 2000). It is a non-dimensional number on a scale from 1 (very weak circulation) to 9+ (very strong mesocyclone). Rank 5 is the minimum for an actual mesocyclone. So, the algorithm is able to detect smaller and weaker storm scale vortices that can still produce severe weather. This is a non-dimensional number with values of 0 - 2300 (weak), 2300 - 3600 (moderate), and > 3600 (strong).

Not all of the wind reports were found to have a circulation associated with them, although some circulations were near numerous reports during their lifetimes. In all, approximately 55% of the reports that were within the coverage of the radars occurred in conjunction with a long-lived circulation. This does not mean that other reports were not associated with any type of circulation though. Numerous reports had circulations that were detected for fewer than four volume scans (thus not meeting the long-lived criterion), and others, while in the radar coverage area, were in areas where there were problems with the velocity data, due to range-folding or far ranges from the radar.

6. SUMMARY OF RESULTS

Some of the major findings are as follows:

- The average CAPE increased dramatically between the initiation point and midpoint of the systems. The greatest concentration of wind reports was generally found near the region of highest CAPE. However, some of the cases didn't reach the midpoint until after they were being driven by mechanisms other than the surface instability and this instability was unable to be realized.

- A significant number of wind reports were not associated with a bowing segment. This signals a slightly new way of thinking about severe wind events. The conventional way to diagnose severe wind outbreaks has almost always been by identifying the bow echo segment. This approach, while valid much of the time, cannot be thought of as the only signal of surface gusts by the operational forecaster.

- Fifty-five percent of the wind reports within the coverage area of the radar sites were associated with a long-lived circulation or mesocyclone. This is likely a conservative estimate as the distance from the radar and bad velocity data prevented the examination of the flow fields around every wind report. Therefore, the conceptual model described by Schmidt (1991) and Bernardet and Cotton (1998) appears to be appropriate for the cases described here. The conceptual model involves an “up-down” downdraft formed by the gust front and enhanced by an upward-directed PGF induced by the cyclostrophic reduction in pressure associated with the mesocyclone. This PGF is responsible for the longevity of severe surface winds, and becomes the dominant force during the nighttime phase of the derecho-producing MCSs.

In summary, we present evidence supporting the hypothesis that severe winds in derecho-producing MCSs are not due to surfacing of a descending rear-inflow jet, but instead by mesocyclones along the squall line that generate strong “up-down” downdraft circulations. The bow-segments of such storms is simply a response to the lowered pressure within the mesocyclone which results in the enhancement of the rear-to-front circulation but is not directly responsible for the surface winds. Such squall lines can be thought of a “factories” for producing mesocyclones which then account for the widespread straight-line wind damage of those storms.

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Table 1. Comparison of significant features for each of the cases.

Case	Surface Boundary	Ave. 925-850 θe (K)	Upper Level Flow	Jet Position
1	stationary front	346	SW	north
2	weak trough	355	WSW to WNW	north
3	cold front	358	W to WNW	north
4	stationary front	342	WSW to W	north
5	trough/warm front	343	W to WNW	split

Table 2. Comparison of average CAPE (J/kg) and 0-6 km shear [(ms^{-1})/(6 km)] for the events near the initiation point and midpoint.

	Initiation CAPE	Midpoint CAPE	Initiation Shear	Midpoint Shear
Average	2820	4000	15.6	13.8