13.4 TORNADOGENESIS WITHIN QUASI-LINEAR CONVECTIVE SYSTEMS.
PART I: RADAR AND STORM DAMAGE ANALYSIS OF THE 29 JUNE 1998 DERECHO

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1. INTRODUCTION

On 29 June 1998 a line of supercells in eastern Iowa evolved into an intense bow echo that subsequently moved southeast into central Illinois. The bow echo spawned numerous F0-F1 tornadoes and produced widespread wind damage. The system initiated upon an east-west oriented quasi-stationary thermal boundary, consistent with the progressive derecho pattern described by Johns and Hirt (1987).

Studies by Martinelli et al. (2000) and Wolf (2000) have documented many characteristics of this system. Their studies have focused primarily on the early stages of this derecho, including the inception of the system in Nebraska and it's transition from a line of supercells into a bow echo. In particular, these studies have documented the evolution and descending characteristics (Trapp et al. 1999) of many radar-detected vortices formed within the system. Many of these vortices formed on the leading edge of the system and produced short-lived F0-F1 tornadoes. Understaning the genesis mechanisms of these circulations is important since recent results (Tessendorf and Trapp 2000) suggest nearly 20% of all tornadoes produced within the United States are associated with quasi-linear convective systems (QLCSs) such as the 29 June 1998 event.

Accordingly, the primary objective of the present study is to investigate the genesis mechanisms of vortices formed along the leading edge of QLCSs. In Part I of this study, we expand upon previous observational studies on the 29 June 1998 event to more completely document the location of wind and tornado damage over Iowa and Illinois during nearly the entire evolution of the system. This will be accomplished through superposition of STORM DATA wind and tornado damage reports on radar data collected by the Davenport, Iowa and Lincoln, Illinois WSR-88D data. In particular, the location and evolution of radar-detected vortices formed on the leading edge of the system will be investigated. This information will help guide numerical simulations of this event that will be presented in Part II.

The synoptic environment on 29 June 1998 is discussed in section 2. Section 3 describes the evolution of this system including an in-depth description of the wind damage reports that occurred with this system in addition to the low-level radar-detected vortices. Description of these vortices will include their mode of development and whether or not they were tornadic. Conclusions are discussed in section 4.

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2. SYNOPTIC ENVIRONMENT

The synoptic environment at 1200 UTC on 29 June 1998 featured a stationary surface frontal boundary that extended through southern Michigan, southern Wisconsin, and central Iowa (not shown). Warm, humid airexisted south of this boundary with temperatures near 25 ^{o}C and dew points near 23 ^{o}C. The synoptic pattern featured weak forcing. At 850 mb southwesterly flow was advecting higher θ_e air into central Iowa indicating a decrease in instability while at 500 mb the flow was northwesterly in this region, with stronger winds being advected into the area, increasing the environmental shear with time. An 1800 UTC composite sounding, created using data from a sounding at Lincoln, Illinois and an initialization of the RUC model gathered at the same time featured 3689 J kg^{-1} of CAPE and 0-2.5 km vertical wind shear of 19.8 m s^{-1} (not shown).

3. SYSTEM EVOLUTION

The evolution of the 29 June 1998 event as observed by Doppler radar is shown in Fig. 1. Evident at 1801 UTC is a line of thunderstorms over central Iowa that are situated over a stationary front. This thunderstorm line, in fact, contained numerous High-Precipitation (HP) supercells (Martinelli et al. 2000). As the supercell line moved into southeastern Iowa, it transistioned into a well-defined bow echo. By 2201 UTC, the bow echo had grown in aerial extent. A cyclonic commahead echo can be observed at 2201 and 2359 UTC suggesting that a significant northern line-end vortex was present at these times. Note that a similar feature is not present on the southern end of the line. Also noteworthy in Fig. 2 is that the stationary front appears to intersect the northern end of the bow echo.

3.1 *Wind Damage*

As can be seen in Fig. 1, much of the wind damage observed over Iowa and Illinois can be attributed to the bow echo. Notice that the aerial extent of the wind damage reports increase from southeastern Iowa into central and southeastern Illinois. This observation is consistent with the bow echo spatial scale increasing with time. Another important observation to be made in Fig. 1 is

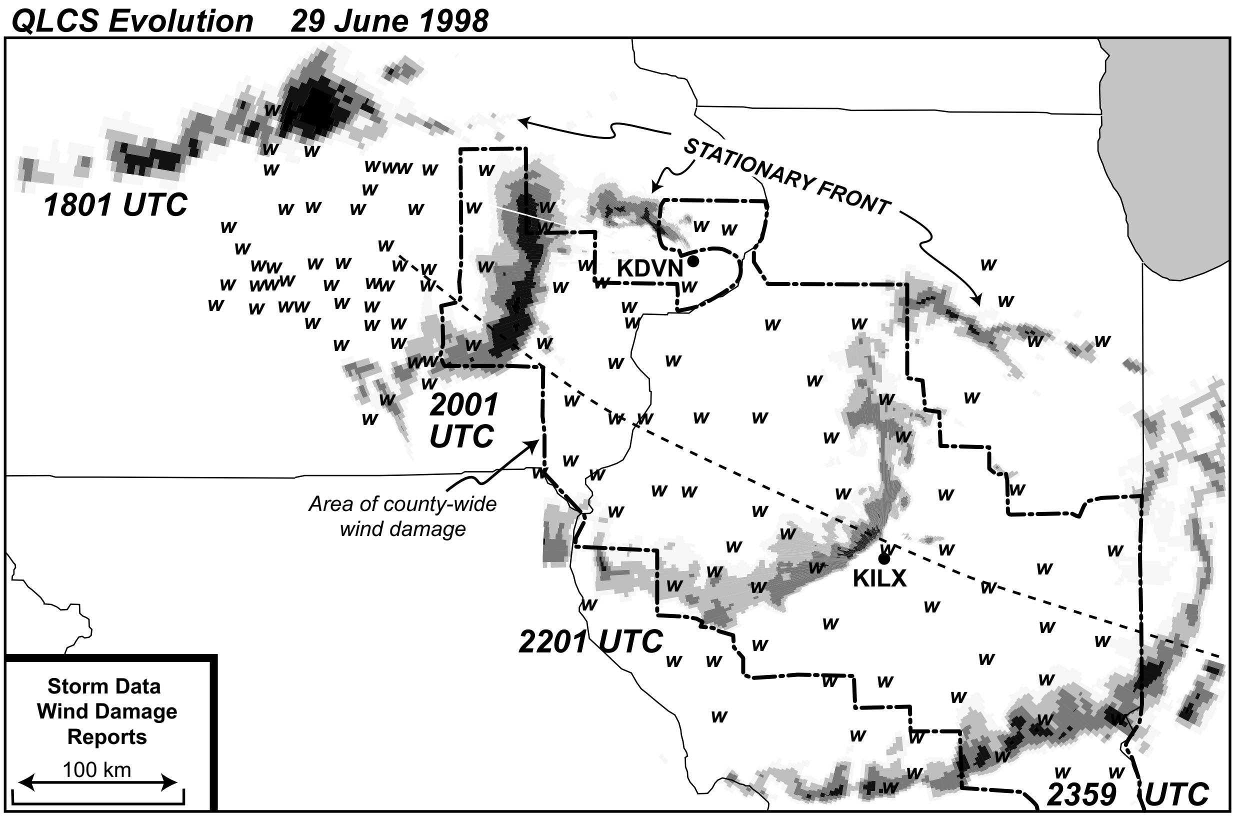

Figure 1. Radar reflectivity data (0.5 degrees) from KDVN and KILX at 1801, 2001, 2201, and 2359 UTC. The W symbols indicate wind damage locations from STORM DATA. The area of county-wide wind damage is indicated with the dash-dotted line. The short-dashed line represents the bow-echo apex location.

that the wind damage appears to occur indiscriminately with respect to the bow-echo apex. In other words, wind damage produced during the entire evolution of the system is observed both north and south of the bow-echo apex.

3.2 *Radar-Detected Vortices*

Detailed analyses of the radial velocity data from the WSR-88D radars at Davenport and Lincoln revealed the existence of at least eleven vortices formed within the QLCS. Their locations are shown in Fig. 2. While consistent with previous studies, it is striking in Fig. 2 that all but one of the circulations was located north of the bow apex. Another interesting observation in Fig. 2 is that all but one STORM DATA tornado reports are collocated somewhere on a circulation path. Thus, the STORM DATA tornado reports can be interpreted with some confidence. Five of the eleven vortices were associated with tornado reports and are therefore interpreted as tornadic circulations. Also notice that a number of the vortices appear to propagate northward relative the the bow apex position.

The detailed structure of the bow echo and vortices formed along it can be seen in Fig. 3. Prominantly displayed are the system-scale features of the bow echo including a 40 ms^{-1} rear inflow jet and a comma-head echo with associated cyclonic line-end vortex having a spatial scale of approximately 40 km. At the leading edge and north of the bow apex are two meso-γ scale vortices. Analysis of the radial velocities suggest that these circulations (labeled #7 and #8) have spatial scales of approximately 5 km. The scale of these vortices is typical of all others shown in Fig. 2.

Detailed characteristics of all vortices shown in Fig. 2 are presented in Table 1. With the exception of vortex #1, all vortices have similar characteristics. Vortex #1 is stronger, longer-lived, and is deeper than any of the other vortices. It's genesis mechanism and subsequent evolution, however, may be different than the other vortices since it was observed to form just south of the intersection of the stationary front and bow echo (see Fig. 2). The remainder of the vortices are clearly low-level, existing in the lowest 2-3 km of the atmosphere. Nearly all of the vortices exhibited average peak rotational velocities of 30-45 m s^{-1}. Vortex lifetime was somewhat variable,

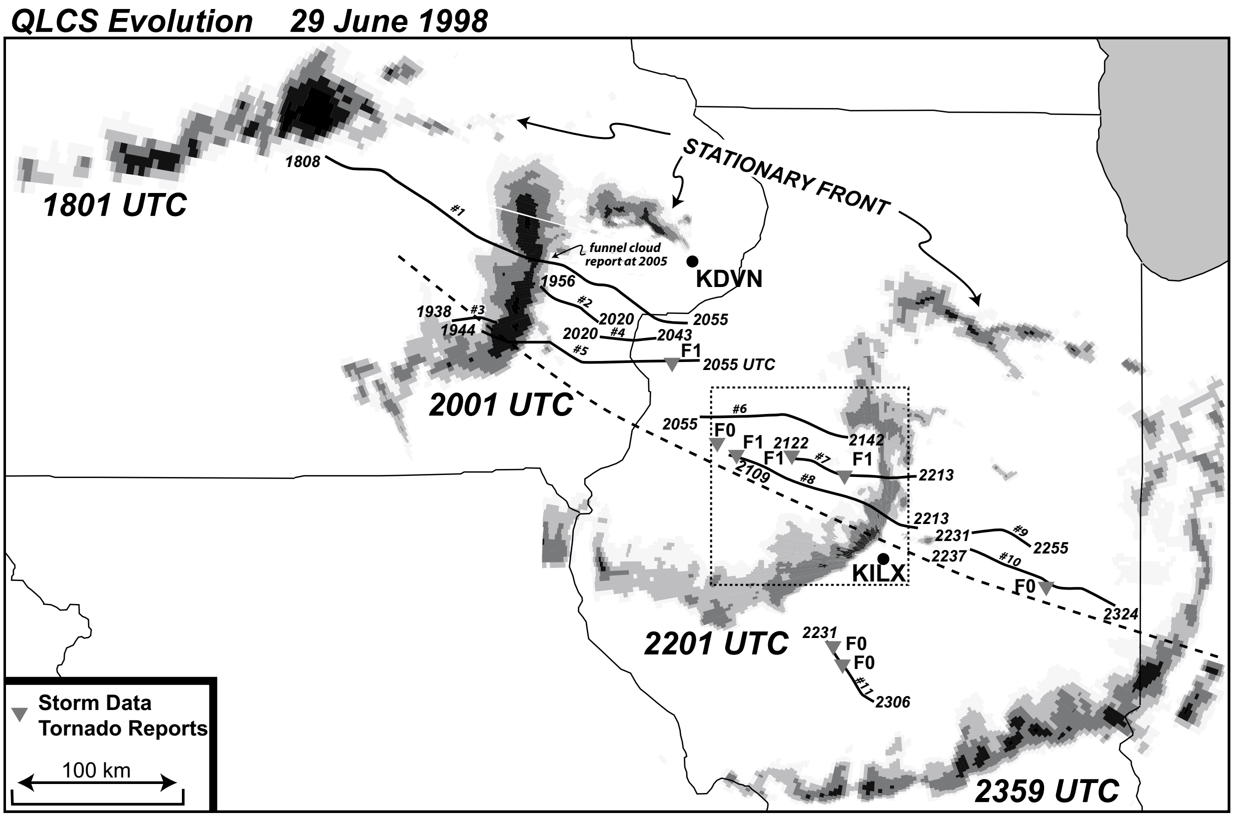

Figure 2. Same as Figure 1 except that radar-detected circulation paths (thick black lines) and STORM DATA tornado reports (gray triangles) are shown. The dashed box indicates the area shown in Figure 3.

however, a majority (60%) of the vortices exhibited lifetimes of between 30 and 60 minutes.

Eight of the eleven vortices were determined to be nondescending, in agreement with the findings of Trapp et al. (1999). Unfortunately, the radar resolution was poor in the case of vortices #9 and #10. Determining vortex mode generation was, therefore, not possible in these cases. All vortices, including the one south of the bow apex, were cyclonic.

4. CONCLUSIONS

The 29 June 1998 derecho initiated in synoptic conditions consistent with the progressive derecho pattern presented by Johns and Hirt (1987). With weak synoptic-scale forcing, large instability and strong low-level vertical wind shear were necessary for the development of this system. This system featured a supercell-to-bow echo transition early in it's lifetime after moving from a supercell-conducive environment to one more conducive to bow echo development.

Expanding upon the work of Martinelli et al. (2000) and Wolf (2000) Part I of this study has documented the wind damage associated with this system in addition to

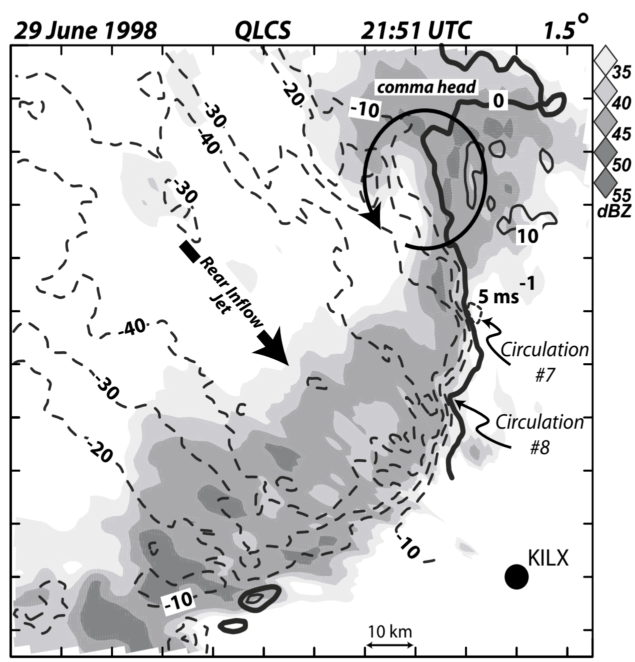

Figure 3. Detailed structure of the bow echo at 21:51 UTC. The domain is shown as a dashed box in Figure 2. Radar reflectivity is in gray and radial velocities (ms^{-1}) are shown as solid (outbound) and dashed (inbound) lines.

Number	Lifetime (min)	Average Peak Rotational Velocity (m s^{-1})	Peak Rotational Velocity (m s^{-1})	Average Height of Peak (km)	Descending?	Tornado	Tornado Strength
1	167	45.2 (±10.3)	65	4.2 (±3.8)	Yes	No	N/A
2	24	33.0 (±4.0)	35	1.5 (±1.0)	No	No	N/A
3	24	38.2 (±3.0)	41	1.8 (±1.2)	No	No	N/A
4	36	33.7 (±6.1)	44	1.9 (±1.2)	No	No	N/A
5	78	36.4 (±8.0)	51	1.2 (±0.8)	No	Yes	F1
6	54	41.9 (±5.8)	52	1.6 (±1.0)	No	No	N/A
7	48	44.0 (±4.9)	50	2.0 (±0.9)	No	Yes	F1
8	72	39.8 (±3.2)	46	1.1 (±0.6)	No	Yes	F1
9	30	30.6 (±7.5)	39	2.0 (±0.8)	?	No	N/A
10	60	29.8 (±6.6)	43	1.9 (±1.2)	?	Yes	F0
11	42	37.7 (±6.6)	43	0.9 (±1.2)	No	Yes	F0

TABLE 1. Detailed characteristics of the eleven radar-detected vortices between 1800 UTC and 0000 UTC. Vortex number consistent with Figure 2. Values in parentheses indicate one standard deviation. Question marks indicate that insufficient radar resolution was available to determine the mode of vortex.

characteristics of eleven radar indicated vortices associated with the 29 June 1998 derecho. In addition to their characteristics, the spatial distribution of these vortices with respect to the bow echo has been shown. In particular, of the eleven vortices documented in this study, ten of them spent nearly their entire lifetime north of the bow apex. While a few of the vortices moved in the same direction as the bow echo, others moved northward relative to the bow-echo apex along the leading edge of the system. All but one of the eight superimposed STORM DATA tornado reports were collocated with a circulation track, lending credence to the STORM DATA tornado locations. This analysis also showed that five of the circulations were tornadic, four of them located north of the bow apex. The distribution of damaging wind reports is much different than for the tornadic circulations. Damaging wind reports were located indiscriminately with respect to the bow-echo apex during most of the QLCS lifetime.

In addition to their spatial distribution, structural details of these vortices have been presented. With the exception of the vortex observed just south of the intersection of the bow echo with the stationary front, these vortices are basically short-lived, low-level phenomena. A vast majority of these vortices appeared to be nondescending, in agreement with Trapp et al. (1999).

The results presented herein and other related published work have forecasting implications. While it appears that tornadoes will more likely form north of the bow apex, issuing the appropriate warnings is still problematic since detection of the short-lived, low-level circulations is difficult. This is further complicated by the fact that their genesis mechanism(s) is(are) still not well-understood. This aspect of the problem is to be addressed in Part II of this study.

5. ACKNOWLEDGEMENTS

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