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1. INTRODUCTION

It is well known that bow echoes often produce swaths of “straight-line” wind damage generally F0-F2 in damage intensity. Fujita (1978) first described the morphology of a radar-observed bow echo and its attendant damage. He described how downburst winds associated with rear inflow descend from an initial tall echo and push the convective cells outward at the apex of the developing bow. Downburst winds generated surface wind damage at the bow apex upon reaching the ground.

Recent observations and numerical simulations (e.g., Schmocker et al. 2000; Trapp and Weisman 2003) have suggested another mechanism that may produce damaging “straight-line” winds in bow echoes. Low-level meso- γ -scale vortices, or “mesovortices”, formed on the leading edge of the bow echo may also produce swaths of straight-line wind damage *north* of the bow apex. Resolution of the damaging wind mechanism(s) within bow echoes requires the superposition of detailed data from damage surveys and Doppler radar. Such analyses have not been published in the literature.

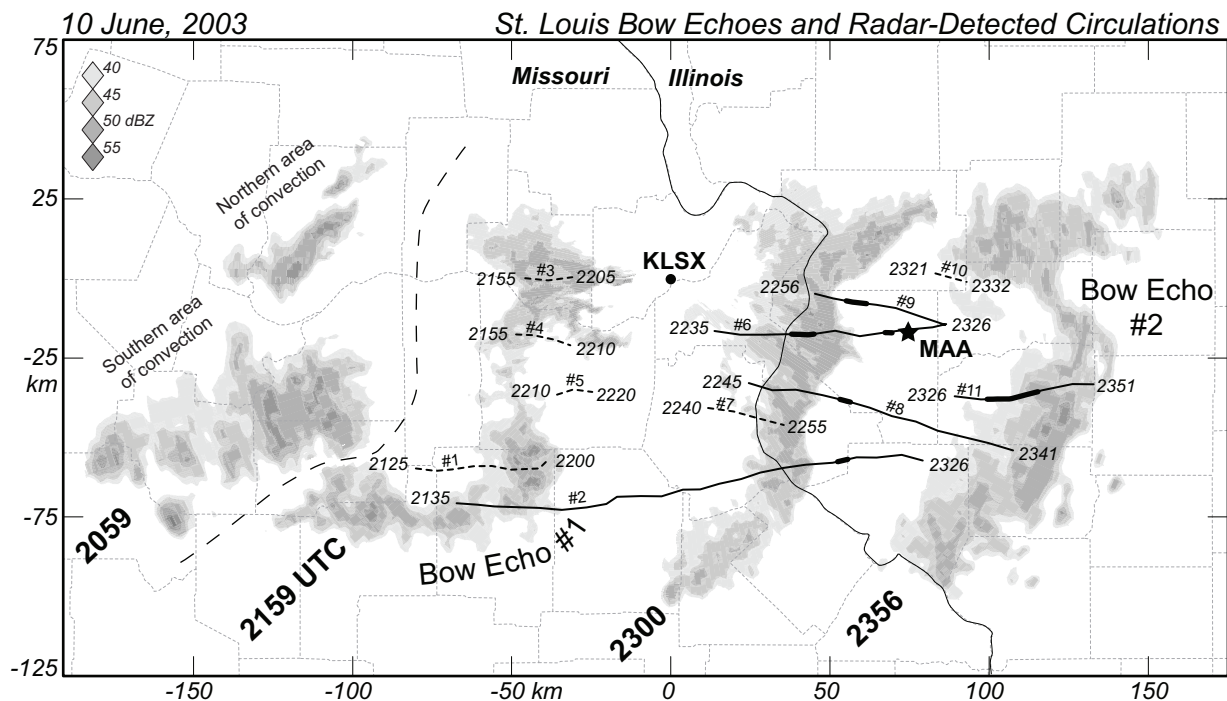


Figure 1. Radar reflectivity data at 0.5 degrees from the KLSX radar. Solid and short-dashed lines indicate positions of tornadic and nontornadic mesovortices, respectively. Tornado times are shown with thick lines. The long dashed line separates the 2059 and 2159 UTC radar data.

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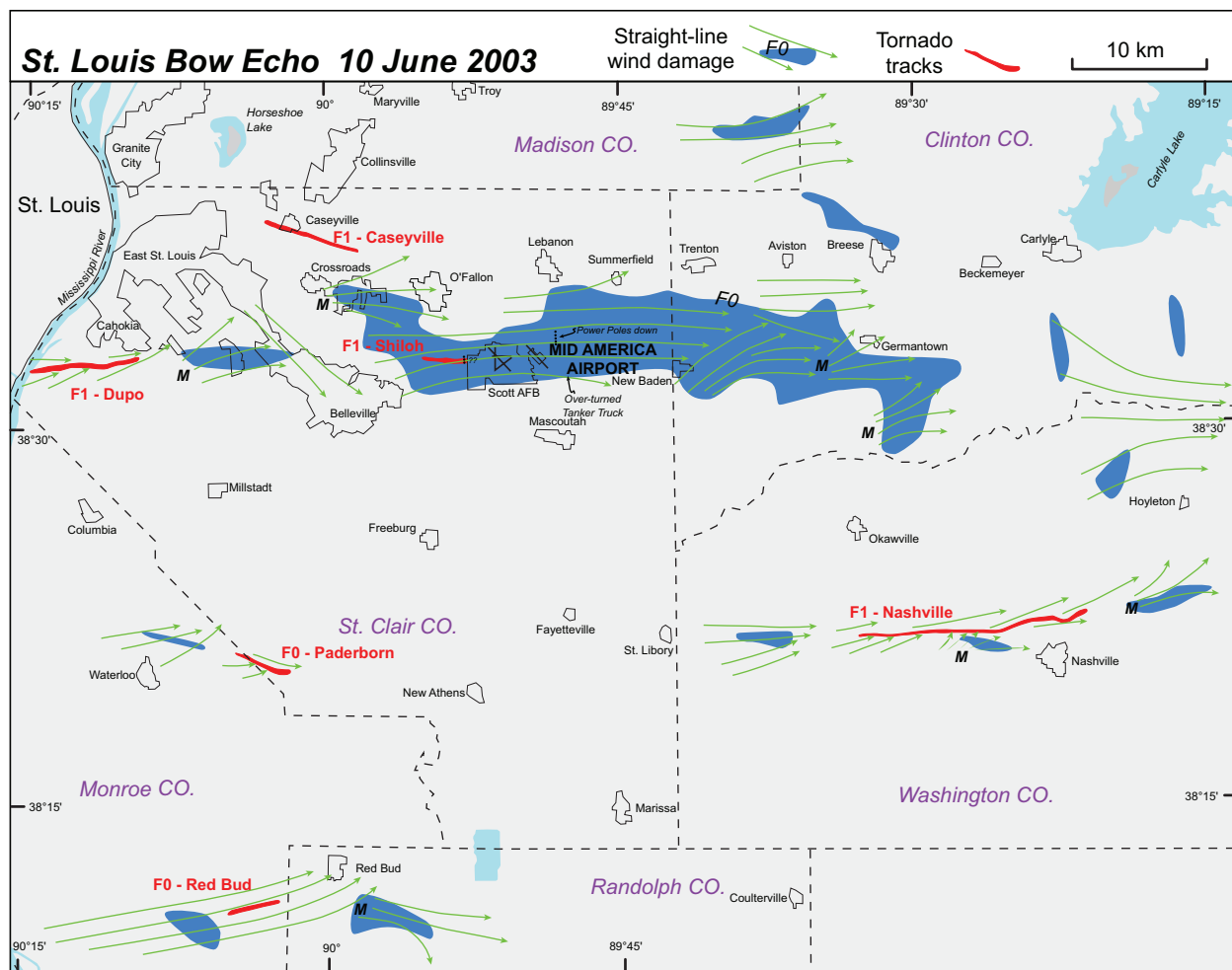


Figure 2. Damage survey analysis over southwestern Illinois. F-scale analysis is shown in blue. Streamlines of damaging winds based on direction of tree fall and building debris are shown in green. Tornado tracks are shown in red. Water (light blue), county lines (long dashed) and towns (solid thin) are also shown. Microburst locations are denoted by the "M"s.

The mesovortices have also been shown to produce tornadoes primarily at or north of the bow echo apex. Przybylinski et al. (2000) have shown that tornadic mesovortices often form at the intersection point of the primary convective system and a nearly perpendicular preexisting boundary. Previous studies (e.g., Funk et al. 1999; Przybylinski et al. 2000; Atkins and Przybylinski 2002; Atkins et al. 2004) have also shown that tornadic mesovortices are relatively strong at low levels and strengthen and deepen with time prior to tornadogenesis. Not all mesovortices, however, become tornadic. The structural differences between tornadic and nontornadic mesovortices are not well understood.

During the afternoon hours on 10 June, 2003, a damaging bow echo moved eastward over the greater Saint Louis area during the Bow Echo and MCV Experiment (BAMEX, Davis et al. 2004). BAMEX occurred from mid May through early July, 2003 and operated out

of the Mid America Airport in Mascoutah, Illinois (location of star in Fig. 1). One of the objectives of BAMEX was to better understand how mesoscale convective systems (MCS) generate damaging winds. The MCS on 10 June 2003 produced a straight-line wind damage swath approximately 50 km in length and eleven mesovortices of which five were tornadic. The objectives of this study are to determine the mechanism that created the 50 km long damage swath and to examine the structural characteristics of the tornadic and nontornadic mesovortices.

2. RADAR EVOLUTION AND DAMAGE SURVEY

The MCS initiated over central Missouri at about 18 UTC, moved eastward and was located approximately 125 km west of the Saint Charles (KLSX) radar by 21 UTC (Fig. 1). The system subsequently produced two bow echoes, the first observed roughly 100 km southwest

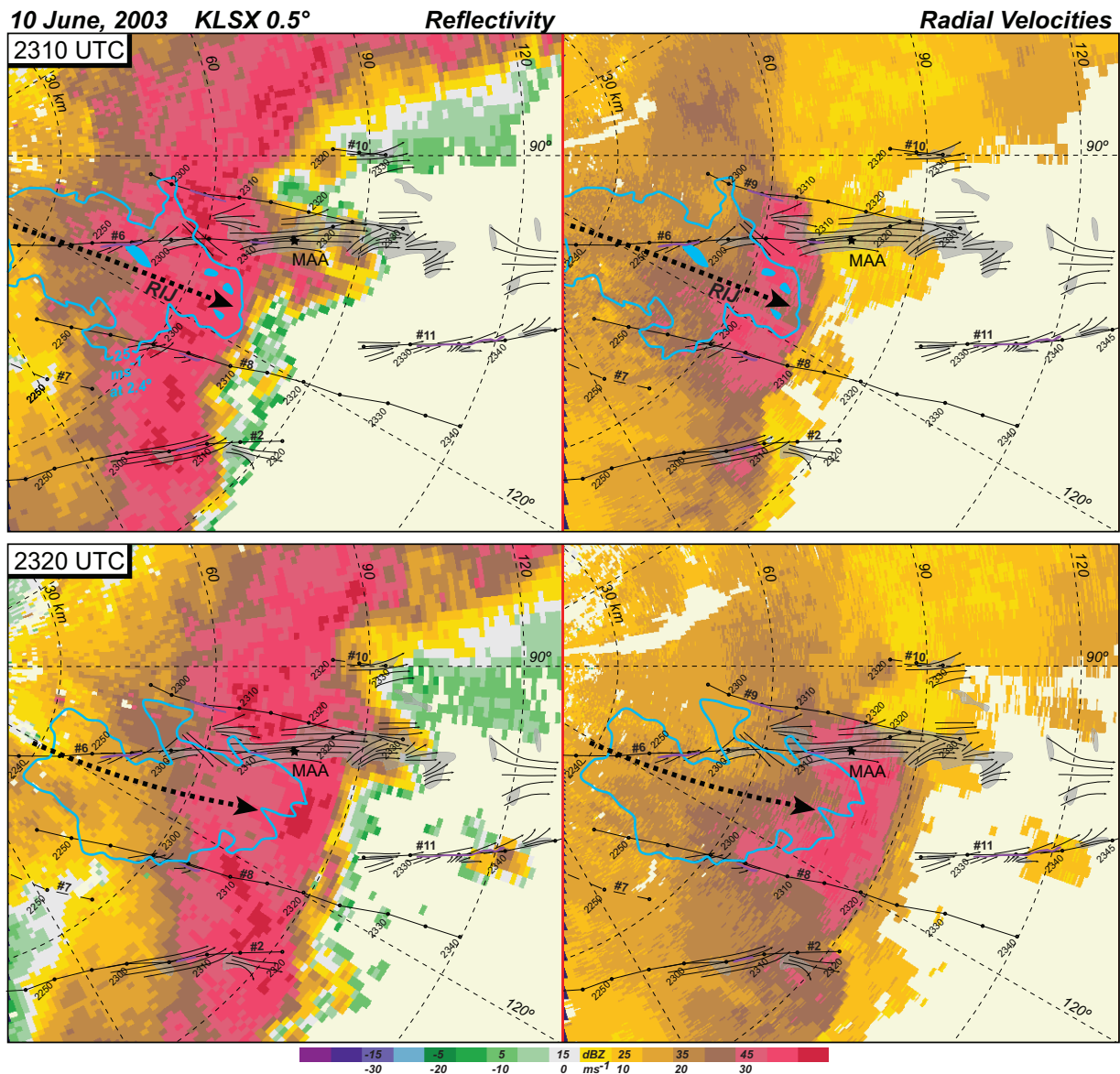


Figure 3. In both panels, F0 or greater straight-line wind damage is shown in gray, tornado tracks in purple and streamlines in black. Mesovortex locations are shown as black lines. The 25 m/s radial velocity contour at 2.4 degrees is shown in blue. The approximate location of the RIJ is shown as a thick dashed black line. Panels (a) and (b) show reflectivity and radial velocities, respectively. MAA is the location of the Mid America Airport.

of the radar (well defined at 2159 UTC) and the second later on in southwestern Illinois. The MCS also produced many tornadic (solid lines) and nontornadic (short dashed lines) mesovortices.

A detailed aerial and ground damage survey of this event was performed. Damage produced by the second bow echo in Fig. 1 is shown in Fig. 2. Clearly evident is a primary damage swath of F0 or greater intensity that was about 50 km in length and 8 km in width. The damage began approximately at 2300 UTC and ended one hour later. Note that the BAMEX Operations Center at Mid

America Airport (MAA) was directly in the damage path! Damage survey efforts also uncovered six F0-F1 tornadoes in southwestern Illinois associated with this convective system.

3. DAMAGING WIND MECHANISMS

In order to understand the mechanism(s) creating the 50 km long damage swath in Fig. 2, the damage survey analysis was carefully superimposed on the KLSX reflectivity and radial velocity data. Results of this analy-

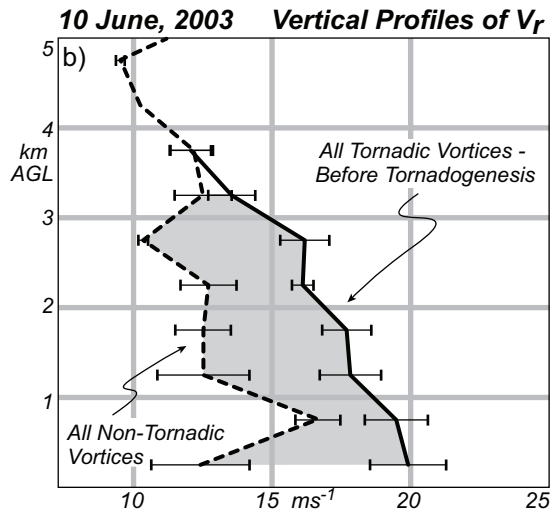


Figure 4. Mean profiles of V_r for the tornadoic (before tornadogenesis) and nontornadoic vortices shown in Fig. 1. Error bars are one standard deviation. V_r is defined as the average of the absolute values of the outbound and inbound couplet maximum.

sis at 2310 and 2320 UTC are shown in Fig. 3. Surface wind damage was being created by 2300 UTC (not shown) on the western edge of the primary damage swath. At 2310 UTC, the convective system was bowing outward between azimuths of 95° and 125° in response to a developing rear inflow jet (RIJ) observed as a core of strong radial velocities at 2.4 degrees. The apex of the developing bow echo is defined herein as the location where the RIJ impinges on the leading edge of the convective system. At 2310 UTC, note that the primary damage swath is *well north* of the bow apex. In fact, the radial velocity data shows that the primary damage swath is generally located on the southern periphery of mesovortex #6. This is even more evident at 2320 UTC where vortices 6 and 9 have moved closer to each other.

Their combined outbound radial velocity maximum in excess of 40 ms^{-1} , is coincident with the primary damage swath location. Interestingly, vortex #6 passed directly over the BAMEX Operations Center at the Mid America Airport and adjoining Scott Airforce Base where wind gusts in excess of 45 ms^{-1} were measured. By 2325 UTC, mesovortex #6 merges with vortex #9 and dissipates after 2330 UTC. After 2330 UTC, the damage swath was likely created by the dissipating merged vortex acting constructively with embedded microbursts evident by the divergent southwesterly flow within the latter part of the primary damage swath. The results in Fig. 3 conclusively show that *low-level mesovortices within bow echoes are capable of producing long swaths of damaging straight-line winds north of the bow echo apex*. In fact, very little damage was observed along the apex of bow echo #2.

4. TORNADIC AND NONTORNADIC MESOVORTEX STRUCTURE

Apparent in Fig. 1 is that all of the tornadoes produced by the MCS were associated with the mesovortices, however, only five of the eleven circulations were tornadoic. An important detection and warning question concerns whether there are any structural differences that discern the tornadoic mesovortices from their nontornadoic counterparts. Indeed, Atkins et al. (2004) found that tornadoic mesovortices within bow echoes tend to be longer lived, stronger at lower levels (0-3 km AGL), and deeper than nontornadoic mesovortices. Analysis of the mesovortices shown in Fig. 1 confirms the findings of Atkins et al. (2004). The mean lifetime of the tornadoic (nontornadoic) mesovortices in Fig. 1 was 56 (19) minutes. When comparing vortex strength (herein defined as the magnitude of V_r , see Fig. 4 caption for definition), the tornadoic vortices were stronger at lower levels as

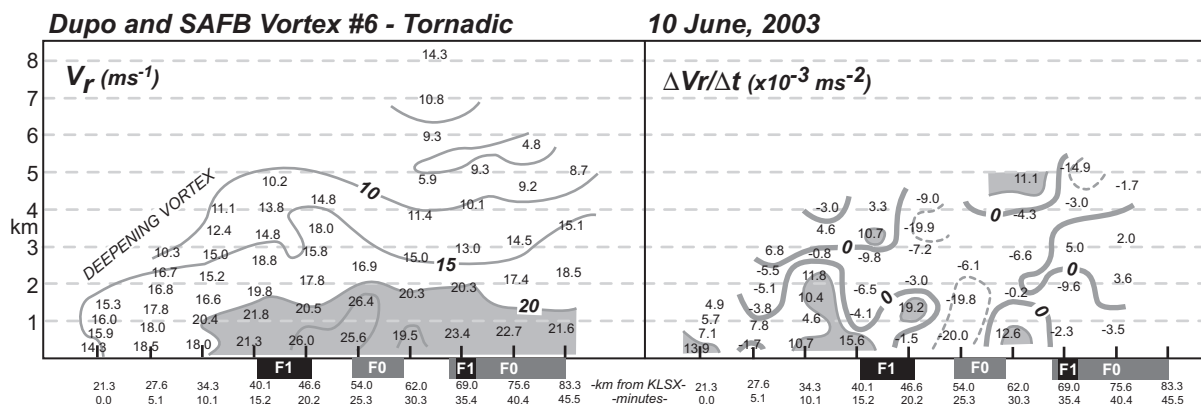


Figure 5. Time-height diagram of (a) V_r and (b) $\Delta V_r / \Delta t$ for tornadic vortex #6 in Fig. 1. Black and gray bars indicate time of tornado and straight-line wind damage, respectively.

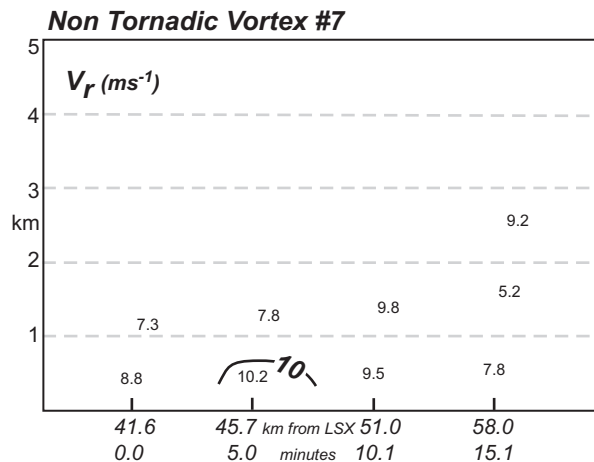


Figure 6. Time-height diagram of V_r for nontornadic vortex #7.

shown in Fig. 4. Plotted are the mean vortex strengths versus height for all tornadic and nontornadic mesovortices. Only data prior to tornadogenesis was used for the tornadic vortices. Fig. 4 clearly shows that vortex strength is larger from 0-3 km AGL for the tornadic vortices.

Another key difference between the vortices is how they evolve with time. The tornadic vortex structure consistently evolved in a manner similar to that shown in Fig. 5. Prior to tornadogenesis, the tornadic vortices were observed to strengthen rapidly at low levels and deepen. The low-level intensification of the vortex is clearly evident in the $\Delta V_r / \Delta t$ field shown in Fig. 5b. Notice the positive values at levels below 3 km AGL prior to the first F1 tornado. Another local maximum can be found at low levels just prior to the second tornado. This deepening and rapid vortex intensification at low levels was not observed with any of the nontornadic mesovortices. Fig. 6 shows the evolution of V_r for nontornadic vortex #7. Clearly, the V_r values are weaker, show no signs of intensification with time, and suggest a shallow vortex relative to the tornadic vortices. The evolution of vortex #7 is representative of the other nontornadic mesovortices.

5. CONCLUSIONS

Detailed damage survey and Doppler radar data were analyzed to better understand the mechanism(s) that created a 50 km long damage swath within the 10 June 2003 Saint Louis bow echo observed during BAMEX. Results of the analysis clearly showed that the damage swath was not located at the apex of the bow, rather it was displaced well north of the apex and was collocated with a mesovortex.

Analysis of the Doppler radar data also confirms the findings of Atkins et al. (2004) in that *it appears to be possible to distinguish between the tornadic and non tornadic mesovortices*. Consistently, the tornadic vortices were longer lived, stronger at low levels (0-3 km) and deepened rapidly just prior to tornadogenesis. The nontornadic vortices did not evolve in a similar manner.

The results of this study suggest that monitoring mesovortices within bow echoes may be an important task in the detection and warning process. Swaths of "straight-line" wind damage may be found north of the bow apex associated with a mesovortex. Furthermore, by monitoring the structural evolution of the vortices, it may be possible to determine which ones will become tornadic. This knowledge would likely lead to improved warnings of damaging winds and tornadoes.

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