7.4 SEVERE THUNDERSTORM RADAR SIGNATURES OF 5 JULY 2002 DERECHO IN FINLAND

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1. INTRODUCTION

On 5 July 2002 a bowing squall line moved over Eastern Finland causing wind damage over a distance of 450 km meeting the criteria of a derecho (Johns and Hirt 1987). The main areas of damage were concentrated along the path of the approximately 100 km wide apex of the bow echo. A ground survey indicated that the area of the worst damage was covered with the patches of F1 or F0 tree damage. Also a few burst swaths of low F2-scale damage were found.

The most significant damage happened about 1.5 h after the mesoscale convective system had become a large scale bow echo. The mean speed of the system was 21 m/s towards the north-northwest. Downwind cells merging with the squall line resulted in the development of very intense storms embedded in the squall line near the location of the rear inflow jet. The objective of this study is to understand the storm structure and radar signatures of the bow echo during the worst damage phase. The synoptic and mesoscale settings of the case are discussed by Punkka and Teittinen (2004).

2. DAMAGE SURVEY

Based on a ground survey at the worst damage area, the downburst wind direction varied from south to east. Typically with F0 and F1 damage, the winds varied from south to south-southeast and the trees had fallen in approximately same direction with 20-30° variation. Some burst swaths of high F1 and low F2 (≥ 50m/s) damage indicated winds with more variability, from south to east. The southernmost surveyed F2 damage track was possibly caused by a tornado, while the other three were confirmed microbursts damage (White dots in fig. 1).

3. BOW ECHO EVOLUTION

The bow echo started as a cluster of thunderstorms in eastern Estonia, took linear structure over the Gulf of Finland while moving northward, and became a distinct large scale bow echo in southeastern Finland at around 15 UTC. A similar radar echo pattern, where a single bow echo moves parallel to quasi-stationary front, is characteristic for progressive derechos (Johns and Hirt 1987). The leading edge of the bow echo had a strong reflectivity gradient and a region of stratiform precipitation was behind the strongest echoes. The bow echo continued to move northward at 21 m/s.

Some isolated thunderstorms developed in front of the squall line. These storms propagated slower, 10-15 m/s, so they eventually merged into the bow echo. Similar cell mergers were also observed in the Berlin derecho (Gatzen 2004). In several derecho cases (Przybylinski and DeCaire 1985) intensification of the squall line and downwind storm cells just before the merging, has been documented. This is probably due to the intensified low level convergence. On 5 July both the downwind cells and the bow echo gained strength just before the merging. This resulted in the development of very intense thunderstorms embedded in the squall line. The most significant cell merger happened at the apex of the bow at 1545-1600 UTC. As the squall line reached the downwind cell, it intensified even more and the bow echo propagation speed temporarily slowed down (Fig. 1a). At 1615 UTC the squall line became wave-like resembling a line echo wave pattern (LEWP) and it had two intense cells (Storms A and B) embedded in it (Fig. 1b). These storms continued moving north-northwest and were associated with the most intense burst swaths over the damage area.

4. RADAR CHARACTERISTICS OF THE MOST INTENSE STORMS

Storm A moved at a speed of 25 m/s causing continuous F0-F1 wind damage during the period 1615-1645 UTC. In the storm path, there were also several small areas of F2-strength microburst damage starting at 1613 UTC. Storm A had evolved into a bow-shape reflectivity structure at 1615 (Fig. 1b). The maximum reflectivity, 55 dBZ, was below 3 km AGL as the core of 50-55 dBZ echoes reached up to 8 km height. The low level reflectivity gradients were high in the apex of the storm scale bow echo indicating the position of the inflow (Fig. 1b). At 1630 UTC a bounded weak echo region (BWER) was evident in the inflow area (Fig. 2b). The reflectivity core of 57 dBZ extended up to 6 km AGL. The storm scale bow echo had become more distinct at low levels resembling a comma-head shape (Fig. 1c). Also the reflectivity gradient at low levels behind the storm had increased as the reflectivity maximums reached 60 dBZ. At 1630, the Kuopio (KUO in Fig. 1) Doppler radar (4.5° elevation angle) measured two inbound velocity maximums of 30-35 m/s with Storm A. At the leading edge strong convergence (25 m/s) was observed at approximately the 2 km height. A velocity difference at 3-5 km AGL in a convergence area ≥25 m/s can be called Mid-Altitude Radial Convergence Signature (MARC). At 1645 UTC the western edge of the storm had a 55 dBZ core reaching high altitudes

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(8 km) while the eastern edge had collapsed. At low levels the storm had lost its bow shape.
The Storm B low level reflectivity structure resembled a storm scale bow echo during the 1615-1645 UTC period (Fig. 1). At 1615 UTC the 55 dBZ reflectivity core reached 8 km altitude. At 1630 storm B had an inbound velocity maximum of 25-30 m/s. At 1645 UTC the storm had collapsed with most of the ≥40 dBZ reflectivities at less than 5 km AGL height. At the same time divergence was found underneath the apex of the storm. An inbound velocity maximum of 30-35 m/s extended from behind storm B to its eastern side. The small area of 35-40 m/s winds was at the eastern edge of storm B.

Storm C formed as downwind storm cells merged with the squall line. It caused continuous wind damage during the period 1615-1645 UTC, but the most widespread damage occurred half an hour later. At 1615 UTC the storm had an elevated reflectivity core of 60 dBZ at 8 km height (Fig. 2e). Storm C possibly had an inflow on its right flank, and also had a BWER at its southeastern edge indicating a supercell structure (Fig. 2f).

All studied storms (A, B and C) had high elevated reflectivity cores. The difference between the precipitation core height and the minimum θ_e height can be used to determine the likelihood of a microburst (Atkins and Wakimoto 1991). In this case the precipitation cores of ≥ 55 dBZ reached 8 km AGL, well above the minimum θ_e at 4 km estimated from the St Petersburg 12 UTC pre-storm sounding (not shown). These cores were above the sounding derived -20°C level at 6.8 km AGL and composed of ice. Descent of a high reflectivity core could not be resolved because of the coarse 15 min intervals of the radar pictures. The most intense damage from Storm A occurred in the vicinity of a rear inflow notch (RIN) and high reflectivity gradients near the leading edge. This combination often signals the location of damaging downbursts (Przybylinski 1995).

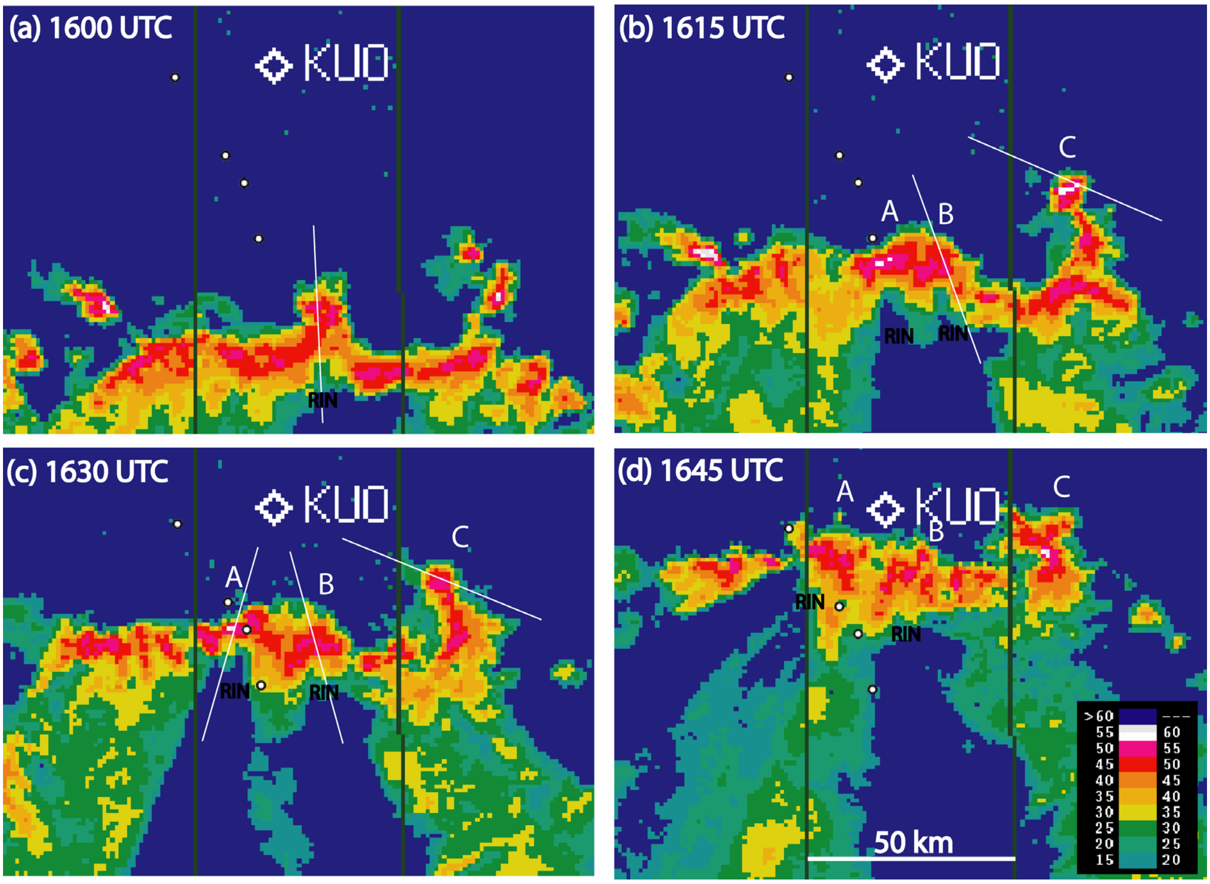

FIG. 1. The 0.5° PPI of reflectivity at a) 1600, b) 1615, c) 1630 and d) 1645 UTC. White lines indicate the positions of cross-sections in Fig. 2. White dots are the location of F2 damages. RINs indicates the position of rear inflow notches. Kuopio radar is marked with letters KUO.

5. SIGNS OF THE REAR INFLOW JET

On 5 July at 15 UTC, behind the eastern part of the bow echo apex, a large region of weak radar reflectivities was found that appears to be a rear inflow notch (RIN). This area of weak reflectivities expanded in size during the next two hours. During the most intense damage phase, two distinct RINs were observed behind the storm scale bow echoes (Fig.1). As the squall line passed its most intense stage, the RIN shrunk in size and eventually disappeared. The RIN is typically located behind the apex of the bow echo, where the possibility for wind damage is highest. It often signifies the location of a rear inflow jet (RIJ). In large bow echoes multiple RINs can be observed (Przybylinski 1995). On 5 July a bookend vortex was found in the western edge during the early stage of the bow echo evolution. Since it was situated far away from the apex and the worst damage, it probably did not influence the strength of the RIJ.

The existence of a mid level jet was evident by both observations and numerical models. In the pre-storm sounding in Central Finland (not shown) the southerly maximum of 27 m/s winds was situated approximately at 700 hPa height. Also the numerical models indicated southerly or southeasterly wind maximums of 20-25 m/s in the area. This mid level jet probably extended to the leading edge of bow echo and possibly influenced the strength of the rear inflow jet.

The Kuopio Doppler radar base velocity data showed some indications of a RIJ. At 1645 UTC the radar (4.5° elevation angle) measured 25-30 m/s inbound radial velocities in the RIN area that extended from about 70 km (up to 6 km height) behind the bow to its apex. Close to the radar the inbound velocities had one maximum between storms A and B, where 30-35 m/s velocities extended from behind the high reflectivity cores (2.5 km AGL) to the apex at 0.5 km AGL. The maximum of 35-40 m/s was on the leading edge of the storm B at approximately 1 km AGL. This velocity data showed evidence that the RIN was linked to the RIJ.

The RIJ typically descends to 2 km AGL as it approaches the leading edge of the bow echo. As the RIJ reaches the strong updrafts and downdrafts, the momentum is transferred vertically to both directions (Przybylinski 1995). The MARC was observed with storm A at 1630 UTC, which has been observed to be a precursor of a descending, elevated RIJ. According to large-scale bow echo simulations in strong vertical wind shear case (Weisman 1992), the RIJ remains elevated at 2-3 km AGL near the leading edge even during the late evolution stages of the bow echo.

In addition to strengthening the downdraft by momentum transfer, the rear inflow jet probably affected the downdraft via evaporative cooling by entraining dry air into the system from behind. Signs of low θ_e air entrainment were apparent in both Storms A and B. At 1600 UTC, after the squall line had merged with the downwind cell, a channel of drier air behind the storm was evident (Fig. 2a). A weak reflectivity vault was also found with Storm A at 1630 UTC, reaching from the trailing edge towards the higher reflectivity at 4-6 km AGL. The reflectivity cross sections of storm B revealed a distinct dry air intrusion from behind the squall line towards the leading edge, at 1615 UTC (Fig. 2c), which had lowered by 1630 UTC (Fig. 2d).

6. DISCUSSION

The 5 July case had the three reflectivity characteristics that Przybylinski (1995) discovered to be typical for the severe bow echoes: the strong reflectivity gradient at the leading edge, RINs and bowing convective line segments. Przybylinski and DeCaire (1985) have documented four different radar echo patterns within derechos. A strong reflectivity gradient at the leading edge, one or more RINs and isolated storms on the downwind side are characteristics for a Type 2 derechos, which have many similarities with the 5 July case. This case also has similarities with the Type 3 systems. During the evolution of a Type 3 systems the RIN often increases in size. Also, intense storms with supercell characteristics are observed near the right rear flank of the large scale bow echo (Przybylinski and DeCaire 1985).

On 5 July all three studied storms had high reflectivity cores to at least 8 km AGL. A strong updraft can hold up a large amount of hydrometeors at high elevations in a thunderstorm. Only a slight change in updraft strength may result in the collapse of the high reflectivity core.

Dry air at the middle troposphere or below cloud base can increase the evaporative cooling and strengthen the downdraft. On 5 July the dry layer was at the level of the downdraft origin at 4 km AGL. Dry air at the downdraft source region is expected to increase evaporative cooling significantly (Duke and Rogash 1991). In this case the θ_e difference between the surface and midlevels was only 16 K, which is less that in several documented wet-microburst cases (Atkins and Wakimoto 1991).

Downward transport of momentum influences the strength of the surface winds when parcels in the dry layer conserve their high horizontal speeds as they descend to the surface (Duke and Rogash 1992). On 5 July, a mid level jet of 27 m/s was found at 3-4 km AGL.

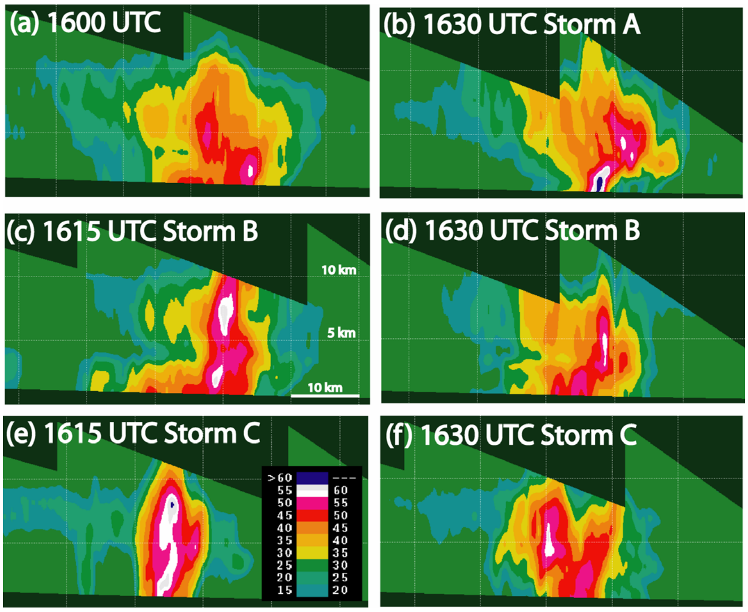

FIG. 2. Reflectivity cross-sections of a) storm merged into the squall line at 1600 UTC, b) Storm A at 1630 UTC, c) Storm B at 1615 and d) 1630 UTC and Storm C at e) 1615 and f) 1630 UTC. The locations of cross-section are marked in Fig. 1.

7. CONCLUSIONS

The 5 July severe bow echo had a strong reflectivity gradient in the leading line which was followed by a stratiform precipitation region. The rear inflow notch was visible in radar pictures as a weak echo region behind the leading line. The most intense damage was situated near the location of the rear inflow jet. Merging of a northward moving bow echo and slower moving isolated cells in front of it resulted in the development of very intense thunderstorms embedded within the squall line. These storms were responsible for the microbursts that caused the most intense burst swaths over the damage area. During the worst damage phase, multiple small scale bow echoes were observed within the squall line. At this time a LEWP was also observed. The most damaging storms that were studied had elevated reflectivity cores and the easternmost storm had supercell characteristics.

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