P6.1 ANALYSIS OF A TORNADIC MINI-SUPERCELL IN FINLAND BY USING DOPPLER RADAR

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1. INTRODUCTION

In the afternoon of 18 August 2004, a tornado developed with a supercell thunderstorm in southern Finland only 17 km from the Anjalankoski Doppler radar. Based on a ground survey the tornado caused a 2.3 km long damage path damaging several buildings and blowing down trees. The cyclonic vortex caused F1 damage.

An average of 10 tornado cases occurs in Finland yearly, but only few of them have been studied. Both non-supercell and supercell tornadoes have been observed in Finland. Severe thunderstorm warnings are issued if severe wind gusts or large hail are expected, but tornado nowcasting has been considered too challenging task for the forecaster. Hence, a tornado warning has never been issued in Finland. Recently, however, significant tornadoes in Finland have been documented to occur with supercells with distinct severe storm radar features well before tornado formation (Teittinen 2002). These storms, or even tornadoes, could be warned for, if the forecaster was given the proper tools and education. Forecasters need to understand how to interpret radar- and environmentally-based tornado precursor signatures in order to be skillful in issuing tornado warnings. These signatures often contain ambiguities which create challenges for forecasters faced with making a tornado warning decision.

The objective of this study is to try to understand why a tornado developed within this particular storm in an environment which is not known to favor tornadogenesis. A particular interest is to find out what kind of severe storm and tornado radar signatures the storm had before tornado formation to help the future warning process.

2. DATA

The Finnish Meteorological Institute 5.32 cm Doppler radar (1.0 degree beamwidth) in Anjalankoski was used as the primary data source in this study. Suitable imagery was produced from the archived raw volumetric data. The radar data were collected at 1.0 degree azimuthal intervals and at the following elevation angles: 0.3, 0.8, 1.7, 2.7, 4.0, 5.5, 8.0, 13.0 and 25.0 degrees. Complete volume scans were available at 15-minute intervals and additional scans at the lowest four elevation angles were available at 5-minute intervals. Because of the low pulse repetition frequency (570 Hz) of the four lowest angles, the maximum unambiguous velocity was 7.58 m/s, thus making the interpretation of velocities at low altitudes complicated. Therefore the dealiasing of velocities was done manually.

3. THE STORM ENVIRONMENT

During 18 August an occluded low over Finland was weakening and moving northeast. The warm and humid air mass stretched from south to Baltic Countries and to southern coast of Finland. Cold advection in western Finland forced the occlusion front of the cyclone to bend back and move southeast. Strong near-surface convergence along the southeast-moving bent-back occlusion initiated the tornado- producing storm. South of the front winds were from southwest and on its northern side from north or northwest.

At the tornado location (based on Anjalankoski radar measurements), the wind profile was characterized by south to southwest winds at surface, veering of the wind in lowest 5000 meters to westerly and backing of the wind above. Deep layer shear was growing as the westerly upper level jet intensified over the area

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(see figure 1). The 0-6 km shear of 22 m/s was adequate for supercells, (Weisman 1996) however the 0-1 km shear of 7 m/s was weaker than typically associated with significant tornadoes (Markowski et al. 2003). Two other storms with mini-supercell features also developed along the surface boundary. No severe weather was observed within these storms.

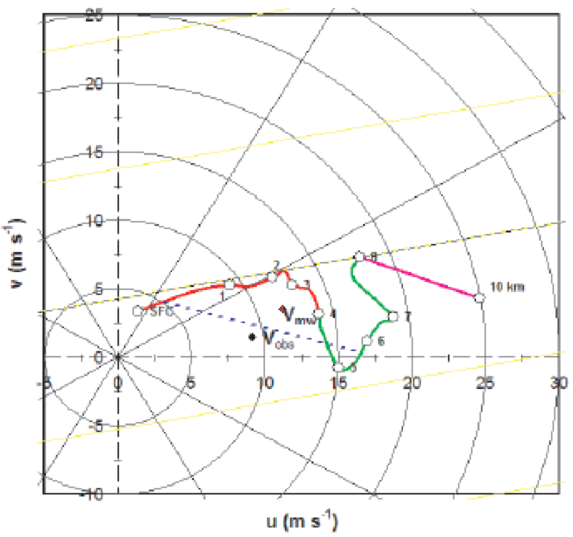

Fig. 1. A hodograph derived from a velocity wind profile derived from the Anjalankoski radar at 1245 UTC just to the north of the supercell track. The observed storm motion is plotted as $\mathbf{V_{obs}}$, $\mathbf{V_{mw}}$ is the mean 0-6 km wind.

4. RADAR ANALYSIS

The parent storm started as a northeastward propagating multicell storm transforming into a supercell as an outflow boundary of a nearby storm reached it from the south. The supercell turned to the right of the mean wind at approximately 30 km/h. The storm track between 1130-1345 UTC relative to the radar is shown in Fig. 2. The storm evolution is visualized in the time-height profile of the maximum reflectivity of the storm at 1130-1400 UTC (Fig. 3). The profile shows contours ascending in time at 1145-1250 UTC indicating updraft growth. Prior to tornado formation the storm echo top increases in height to its maximum. Reflectivity increases over time above the freezing level indicating hail or graupel growing in size. After the tornado at 1300-1400 UTC, the reflectivity maximum reaching the ground suggests possibly heavy rain, hail or graupel or strong outflow winds at the surface (Brown and Torgerson 2003). Within this storm, hail was not reported.

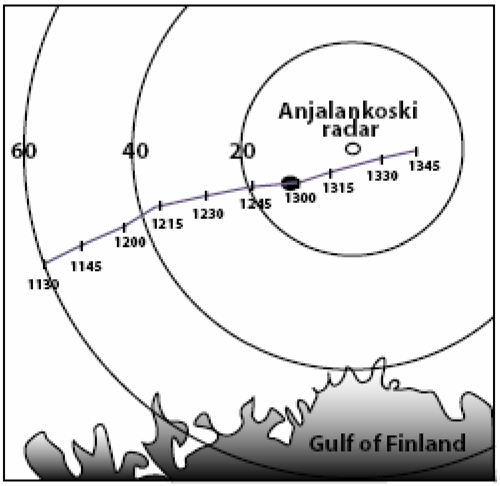

Fig. 2. Storm track defined by the maximum reflectivity in the storm volume from 1130 UTC to 1345 UTC. The storm reflectivity maximum location at the tornado time (at 1255-1300 UTC) is denoted by black circle. The rings are 20, 40 and 60 km distance from the Anjalankoski radar.

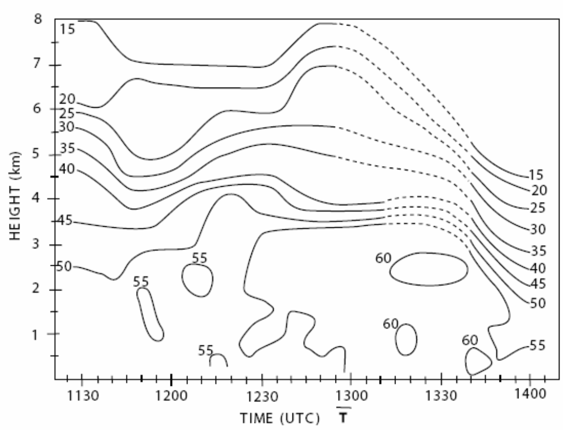

Fig. 3. Time-height representations of data for the storm on 18 August 2004, with contours of reflectivity dBZ. Tornado time (denoted by T) is 1255-1300 UTC. Dashed line is the assumed isolines when the storm is close to the radar.

The supercell thunderstorm produced a distinct hook echo during (Fig. 4) and up to 45 minutes prior to tornadogenesis. A Bounded Weak Echo Region, BWER, became visible by radar during the storm's tornadic phase (Fig. 5). The tornado was situated in the tip of the hook. The diameter of the storm defined by 15 dBZ reflectivity contour was 20 km and the cloud top generally below 8 km. While the echo top was initially above the strongest reflectivity gradient above the storm main core, it moved over the bounded weak echo region during the time of the tornado. A shifting of an echo top toward the updraft flank is an indication of a storm becoming severe (Lemon 1980).

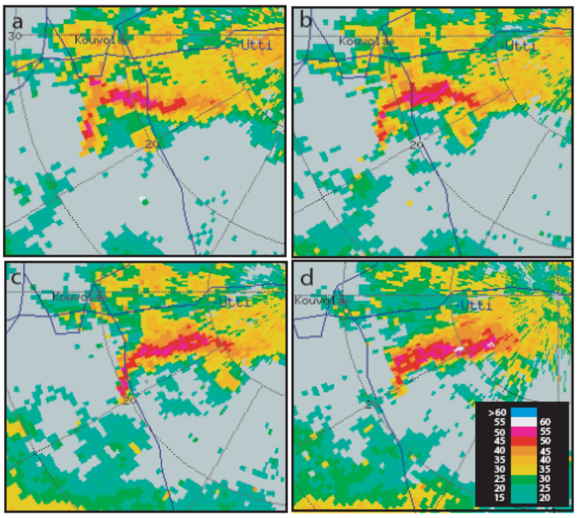

Fig. 4. PPI of reflectivity at 0.3˚ elevation at a) 1245 b) 1250 c) 1255 d) 1300 UTC. The tornado is at ground 1255-1300 UTC.

Overall, the Doppler velocity data showed a mesocyclone signature associated with the hook echo. The mesocyclone was convergent at the 400-500 m height and was successively less convergent with increasing height indicating that the mesocyclone was coincident with an updraft. The presence of tornadic vortex signature (TVS) appears to have biased the apparent parent mesocyclone circulation center. The observed velocity pattern resembles the simulated Doppler velocity pattern of Brown and Wood (1991) in a case where the TVS peak tangential velocity is 2 times that of a convergent mesocyclone and the location of the TVS center is closer to the edge of the mesocyclone core region. A divergence pattern behind the TVS was observed, which appears to be a rear-flank downdraft (RFD).

Ten minutes before the first tornado report the Doppler velocity pattern showed a mesocyclone signature which had stronger circulation maximum close to ground. At the 1.3 km height, the mesocyclone core diameter was 3.5 km. A TVS had already descended to the ground, which is pronounced at the 0.9 and 1.3 km height, where there was strong divergence close to the TVS and behind (right of) the tip of the hook. At 1.7 and 1.2 km height, 5 minutes later, weak anticyclonic rotation in the divergence area at the tip of the hook was observed (Fig. 6a). At the tornado time, 1255 UTC, the TVS tilts in height towards the mesocyclone center (Fig. 6b and 6d). At the 400 m height the TVS is situated at the tornado starting point and shows pure cyclonic rotation (Fig. 6d), while at 1.0 km height the rotation is divergent (Fig. 6b). At the tornado dissipation time at 1300 UTC (not shown) the TVS is still apparent at 900 m height but the rotation (with center over the end point of the tornado damage track) weakened considerably closer to the ground.

Within the mesocyclone, the measured peak tangential velocities were ± 11 m/s. Although the tornado was weak in strength and its diameter was less than 200 meters at the ground, the radar measured maximum Doppler velocity difference within the TVS of 20 m/s. This value is less than the mean maximum differential velocity of 36 m/s observed with tornadic TVSs in the United States (Marzban 2002). The TVS underestimates the tornado peak tangential velocity and overestimates its radius owing to the small vortex within a larger sample volume (Brown and Wood 1991). Both mesocyclone signature and TVS had spatial and temporal continuity for at least four 5-minute time steps and three elevation angles before and during the tornado.

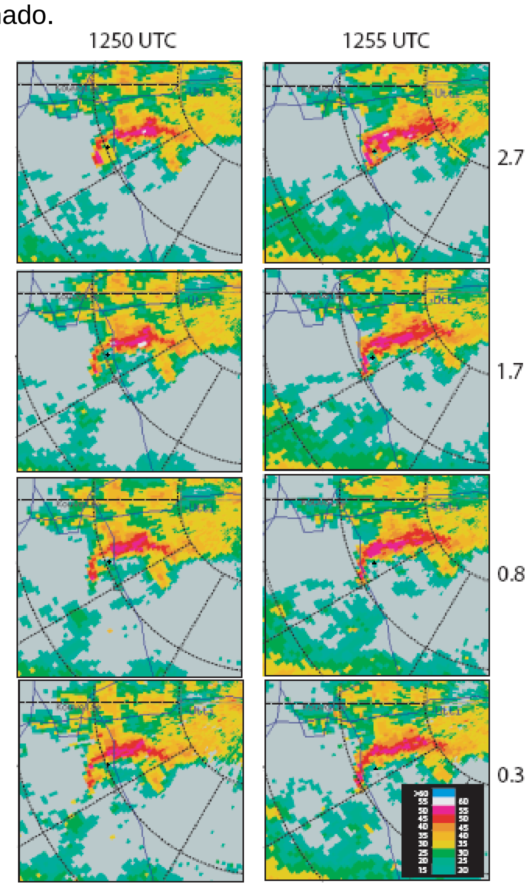

Fig. 5. PPI of reflectivity at 1250 and 1255 UTC at 0.3˚, 0.8˚ 1.7˚ and 2.7˚ elevation.

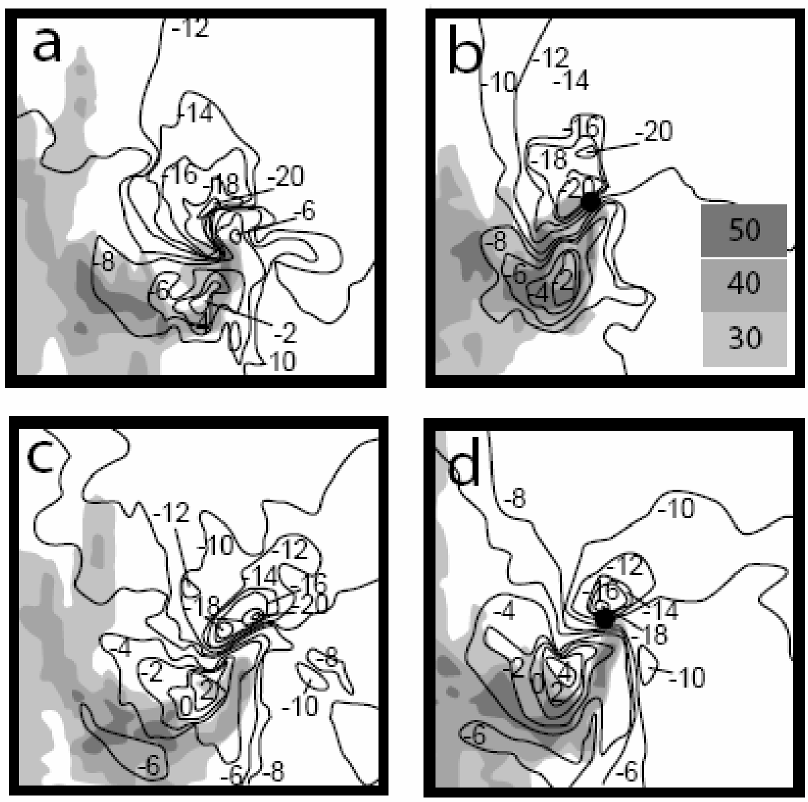

Fig. 6. B-scan picture of Doppler velocity (contours) a) 1250 UTC at 2.7˚ b) 1255 UTC at 2.7˚ c) 1250 UTC at 0.8˚ and d) 1255 UTC at 0.8˚ elevation. The shaded area is the radar reflectivity in dBZ. The radar is situated to the left of each panel with azimuth increasing from 210˚ at top of panel to 270˚ at bottom. Range increases along the bottom of each panel from 5 to 35 km from the radar. The tornado damage path starting point is denoted in 1255 UTC pictures (b and d) by a black circle.

5. SUMMARY

The parent storm started as a northeastward propagating multicell storm transforming into a supercell. The formed supercell moved right of the mean 0-6 km wind. A vertical wind profile measured from the Anjalankoski radar indicated that the 0-6 km shear was able to explain why a supercell formed, however the 0-1 km shear was weaker than typical values associated with significant tornadoes. It is important to note that many significant tornadoes have been documented with 0-1 km shear values equal to or less than found here. It is possible that the supercell encountered higher 0-1 km shear values as it encountered an outflow boundary from the south. A BWER was observed during the tornado. Also the hook echo was pronounced 45 minutes before and during the tornado. The Doppler velocity data showed both mesocyclone signature and TVS with spatial and temporal continuity. No severe storm or tornado warning was issued. However the signs of a supercell thunderstorm were present well before the tornado formation and with close monitoring of individual storms, a severe thunderstorm warning could have been given.

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