P10.2 SUBTLE RADAR SIGNATURES IN THE WEST BROOKFIELD, MA TORNADO OF 23 JULY 2002

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1. INTRODUCTION

Tornadic storms in New England tend to be subtle and difficult to detect. The F1 tornado that occurred in West Brookfield, MA on 23 July 2002 was no exception. On that day, a cold front was moving through western New York and a weak short wave trough was moving through the eastern Great Lakes. Convective Available Potential Energy (CAPE) and vertical wind shear were such that multicellular storms, in the form of a squall line, were expected over southern New England. Indeed, a squall line did form. A weak F1 tornado formed on a break in the Line Echo Wave Pattern (LEWP). It is theorized that this occurred at the apparent intersection of a rear flank downdraft and a developing outflow boundary, which may have helped ‘spin up’ the tornado. The tornado was very short-lived and occurred before the rain arrived.

WSR-88D imagery displayed a short-lived weak hook echo, associated with a gate-to-gate couplet of 51 knots at 0.5 degrees, 44 nm northwest of the radar. This signature lasted for only one volume scan and based on spotter reports and eyewitness accounts, it occurred shortly after the tornado had already touched down. Although classified as a weak tornado, it managed to lift water 30-50 feet into the air from a lake and tear the roof off a house, nailing it to a tree across the street.

This presentation will show the radar signatures associated with this weak tornado and discuss how low-level influences, such as outflow from adjacent storms, may have played a key role in its evolution. Examining extremely subtle radar signatures will aid forecasters in improving tornado detection and warnings.

2. SYNOPTIC AND PRE-STORM OVERVIEW

Several factors indicated the potential for severe weather during the afternoon of 23 July 2002. At 1200 UTC a 500 hPa trough was approaching the St. Lawrence River with a vorticity maximum in Quebec and a lobe extending southwestward into lower Michigan (Fig. 1). A well defined cold front stretched across New York (Fig. 2), with dew point temperatures in the 70°F to 72°F range head of it in western New England and a very sharp dew point gradient behind it. The 1200 UTC sounding from Upton, NY (on Long Island) depicted an already very unstable environment, with a Total Totals Index of 50 and a Lifted Index of –3.7. Winds were unidirectional, from the WSW and speeds were in the 30 to 35 kt range from 700 to 500 hPa with 25 kt at 850 hPa. There was a lot of dry air through the column, which could help aid the potential for microbursts.

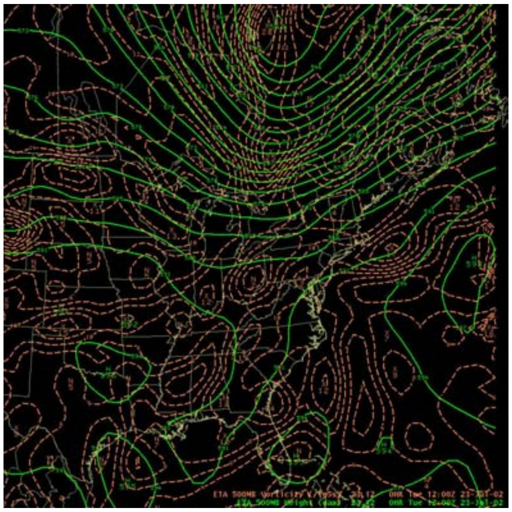

Figure 1. 500 hPa heights (dam) and vorticity (10^{-5} s^{-1}) at 1200 UTC on 23 Jul 2002, as initialized by the ETA model.

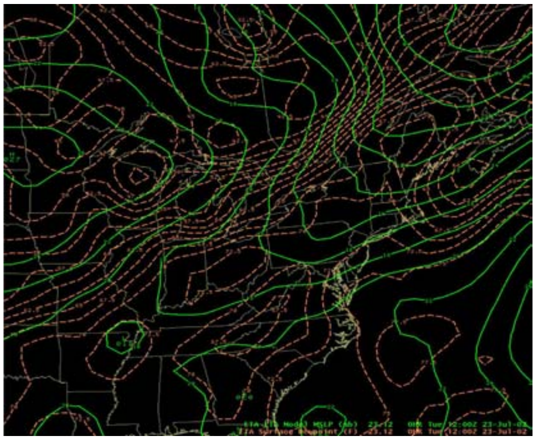

Figure 2. Surface Mean Sea Level Pressure (hPa) and 1000-500 hPa thickness at 1200 UTC on 23 Jul 2002, as initialized by the ETA model.

The 0-3 km storm-relative helicity was 130 $m^2 s^{-2}$ with a straight-line hodograph (not shown); somewhat more veering of the wind was noted in the 3-6 km portion of the hodograph. The highest CAPE forecast by the ETA model was 2350 J kg^{-1} over Connecticut, at 1800 UTC, with only 1500 J kg^{-1} over western Worcester County, MA. The 0–4 km wind shear, from BUFKIT (Mahoney et al. 1998), was 13 m s^{-1} at 1800 UTC. Using a chart based on Weisman et al. (1996) the vertical wind profiles were such that multicellular storms were the expected type of convection (Fig. 3). With surface heating occurring, a narrow vorticity lobe moving across north central New England during the late afternoon, and an approaching cold front, forecasters expected a squall line to form in eastern New York and move into southern New England. Because helicity values were below 150 $m^2 s^{-2}$, tornadoes did not appear to be a main concern, although it was felt that an isolated one could not be ruled out, if some local effects could help induce a spin-up.

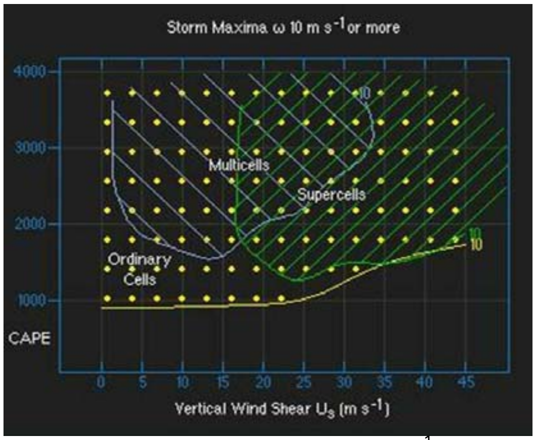

Figure 3. With 0-4 km shear of 13 m s^{-1} and a CAPE in the range of 1500 – 2350 J kg^{-1}, multicellular storms were expected to form. Weisman et al. (1996)

3. WHAT OCCURRED / STORM DAMAGE

An organized squall line formed early in the afternoon (Fig. 4) and by 1900 UTC there were bowing segments (not shown). As the squall line moved over southwestern Worcester County, MA, both a strong microburst and a very short-lived F1 tornado were produced at 1915 UTC in West Brookfield. There were no injuries. The tornado had a path width of 75 yards and a path length of only 0.4 miles. The tornado formed over the northeast portion of Lake Wickaboag and traveled to the east, dissipating just to the east of Wickaboag Valley Road. Most large trees were blown down from southwest to northeast, but there was evidence of trees blown to the north and northwest on the north side of the lake, which was likely related to the circulation center over the eastern portion of the lake. Eyewitnesses reported that a curtain of water from the lake was drawn 30 to as much as 50 feet high in the air. This traveled east and struck a house by the lake, causing its roof to fly off and become nailed to a tree across the street (Fig. 5 and 6). Interestingly, every person interviewed recalled that the wind damage occurred before any rain fell. As will be shown in the radar imagery, the tornado occurred on the leading edge of the bowed segment.

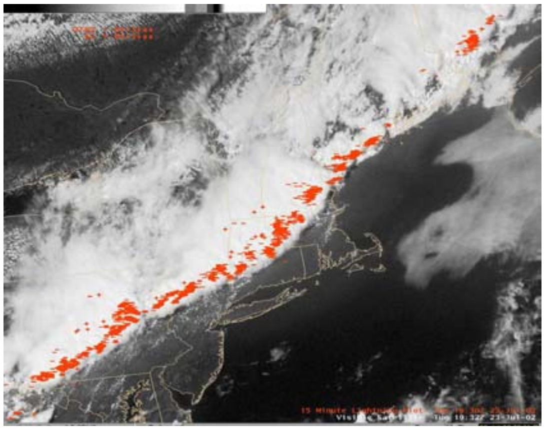

Figure 4. Visible satellite photo of squall line at 1932 UTC on 23 Jul 2002, with cloud-to-ground lightning strikes superimposed in red

The same storm cell was responsible for more damage in the town of Spencer, two towns to the east of West Brookfield. Large trees were uprooted, some landing on cars, houses, and other structures. Wind speeds approaching 100 mph were estimated based on the type of damage seen. From a ground survey, it was determined to be a microburst, though damage from a weak tornado could have been masked by the microburst damage.

Figure 5. Roof blown off house adjacent to Lake Wickaboag. Photo by Glenn Field.

Figure 6. Part of the roof was nailed to a tree across the street. Photo by Glenn Field.

4. RADAR IMAGERY INTERPRETATION

Fig. 7 shows the 0.5° elevation Base Reflectivity (REF) and Fig. 8 shows the 0.5° elevation Storm Relative Motion (SRM) image from the WSR-88D, located to the east in Taunton, MA. At this elevation, the beam, in a standard atmosphere, is centered on 4175 ft. MSL at West Brookfield, MA. While there are several notable features in this radar image, including the cell approaching Longmeadow, MA, and the curved shaped cell just west of Wilbraham, MA, the storm producing the F1 tornado is a far less impressive storm in the center of Fig. 7, approaching West Brookfield, MA. A bowing line segment stretches from Barre, MA in the north central part of the image, southward to West Brookfield, in the center part of the image, southwestward to near Palmer, MA. The tornado was right at the leading edge of the reflectivity, near the cross-hair for the label of West Brookfield.

Similarly, the Vertically Integrated Liquid (VIL) image noted stronger cells associated with other portions of the line. At the time of touchdown, the VIL was 1 kg m^{-2} (not shown). However, a very broad and intense storm was located well to the north of West Brookfield. Five minutes later, at 1920 UTC, the VIL (Fig. 9) in that storm had increased to nearly 50 kg m^{-2} near Barre, MA and was the highest on the radar screen.

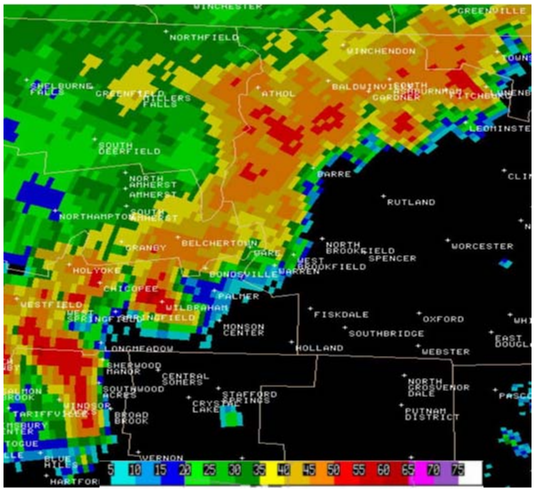

Figure 7. 0.5° Base Reflectivity from the Taunton WSR-88D, at 1915 UTC. West Brookfield is in the center of the image.

Figure 8. 0.5° Storm Relative Motion from the Taunton WSR-88D, at 1915 UTC. West Brookfield is directly to the west of Spencer.

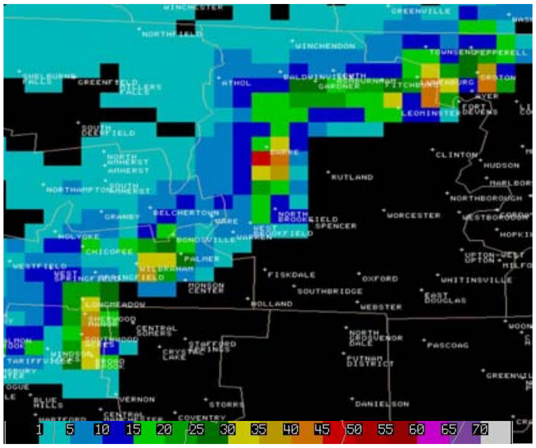

Figure 9. Vertically Integrated Liquid image from the Taunton WSR-88D, at 1920 UTC.

It is theorized that this cluster of cells had created an outflow boundary which had spread southward and was in the vicinity of West Brookfield around 1915 UTC. This was an important cluster of storms. In Fig. 7, note that there seemed to be a northwestward extension to this cluster (seen in the yellow shades on the REF) to near Greenfield, MA, forming a broad-scale comma-shaped feature. To the south of this, a strong apparent rear-flank downdraft took shape. Fig. 10 shows the 0.5° Base Velocity image at 1915 UTC. One can readily detect a large swath of 50-64 knots inbound (northwesterly) winds, pointed right toward West Brookfield, MA, creating the bowing of the line.

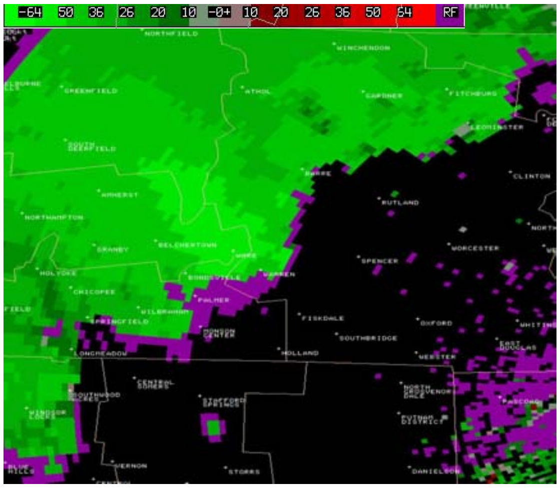

Figure 10. 0.5° Base Velocity image from from The Taunton WSR-88D, at 1915 UTC.

At 1920 UTC, the Taunton WSR-88D showed a small-scale hook in the REF (Fig. 11), most noticeable at 1.5° (around 9300 ft MSL at West Brookfield, MA) and a corresponding gate-to-gate velocity couplet in the SRM (Fig. 12), at 0.5°. Both were on the leading edge of the bow. Presumably, this is a result of the horizontal vorticity already present (due to the vertical wind shear) being stretched and lifted higher into the atmosphere.

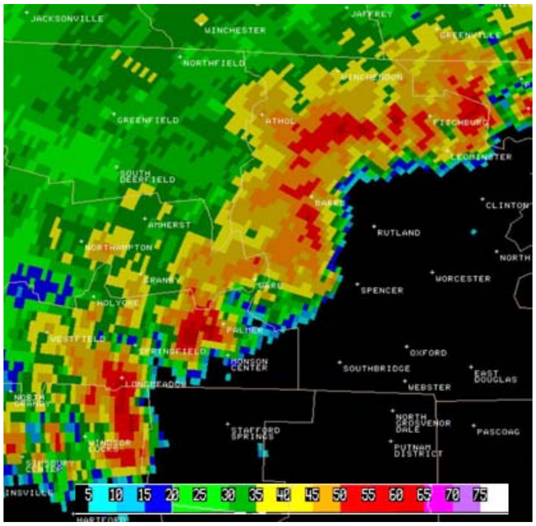

Figure 11. 1.5° Base Reflectivity image from the Taunton WSR-88D, at 1920 UTC. Note the hook appendage on leading edge west of Spencer.

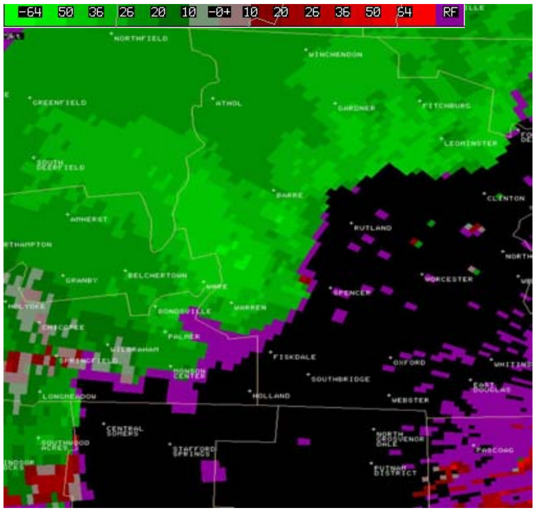

Figure 12. 0.5° Storm Relative Motion image from the Taunton WSR-88D, at 1920 UTC. Note green/red couplet in center of image.

The SRM showed a gate-to-gate couplet of 51 knots (35 knots inbound and 16 knots outbound) at 44 nm northwest of the radar. This signature lasted for only one volume scan at the lowest elevation angle and did not appear until 1920 UTC at the 0.5° angle, after the tornado had struck, according to detailed timing from eyewitness accounts. This minimal mesocyclone signature was evident at 1.5° (higher up) at 1925 UTC.

It is hypothesized that the larger storm to the north, near Barre, had created an outflow boundary, which served as the focus for the tornado spin-up when the rear-flank downdraft intersected it. This is very similar to the case documented by Schmocker et al. (2000), which showed how "an outflow boundary appeared to cause a dramatic change in the local low-level vertical wind shear profile and storm-relative helicity, leading to a more favorable environment for low-level mesocyclogenesis along a convective line as it intersected this outflow boundary." This expanded upon work done by Maddox et al. (1980), which showed how low-level boundaries enhance the low–level convergence, vertical vorticity, and storm-relative helicity.

The Taunton WSR-88D did not show a strong couplet at 1915 UTC and only a minimal mesocyclone at 1920 UTC and higher up at 1925 UTC due to: 1) the tornado circulation may have been too small (spatial resolution); 2) the rotation may have been too weak to detect; 3) the radar beam may have been overshooting the best part of the circulation, which might have been much closer to the ground initially; 4) temporal resolution issue – the tornado lasted less than a minute, yet the imagery is every 5 minutes. The new VCP12 has reduced the volume scan time to nearly 4 minutes, as of this writing. Radar imagery obtained from the Albany, NY WSR-88D indicated that no coherent rotation couplets were present through 1921 UTC, although the area was in the range-folded region at the time of the tornado. Then, at 1926 UTC, a strong gate-to-gate coupled formed at 0.5° just to the north of Spencer (Fig. 13). The rotation was >50 knots outbound and 35 knots inbound. This was at an elevation of 12,700 ft. MSL at that location. Taunton radar at 1925 UTC did not show a significant signature at that level (roughly 2.4°).

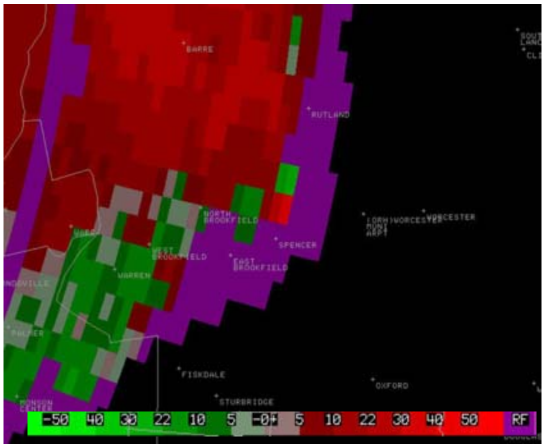

Figure 13. 0.5° Storm Relative Motion image from the Albany, NY WSR-88D, at 1926 UTC. Note the strong couplet north of Spencer, MA.

5. SUMMARY

A cold front moving into an unstable air mass produced a squall line, which was well anticipated. A few segments of that line produced bowing segments and at 1915 UTC, a F1 tornado occurred at the leading edge of the bow in West Brookfield, MA. It has been shown that an outflow boundary may have been present, from a strong storm to the north of West Brookfield. When the strong northwest winds on the rear flank of this storm system intersected the boundary, the tornado spin-up was induced. The stretching of the horizontal vorticity that was already in place in the environment may have been why the radar signatures showed the circulation center at higher and higher elevation angles with time. At the time of the touchdown, which lasted for less than one minute, it was nearly impossible to identify a circulation pattern. Given the Albany, NY WSR-88D signature 11 minutes later, it is possible that some of the downburst damage in Spencer, MA, may also have been tornadic. Tornadoes in New England tend to have subtle radar signatures and this was no exception. Examining extremely subtle radar signatures will aid forecasters in improving tornado detection and warnings.

6. ACKNOWLEDGEMENTS

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