14.5 **THE WASHINGTON DC TORNADO OF 24 SEPTEMBER 2001: PRE-STORM ENVIRONMENT AND RADAR PERSPECTIVES**

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1. INTRODUCTION

During the afternoon of 24 September 2001 between 2:30 PM and 6:00 PM Eastern Daylight Time (EDT), National Weather Service (NWS) forecasters at the Weather Forecast Office (WFO) in Sterling, Virginia, were faced with a challenging tornadic storm threat (in addition to a flash flood threat that later materialized that evening but will not be discussed here). That afternoon, two separate supercell thunderstorms (qualifying as "mini"-supercells according to Burgess et al. 1995) accounted for a total of five tornadoes which touched down across portions of northern Virginia and central Maryland (see Fig. 1). One supercell storm produced a nearly 30 km-long F3 tornado track. This "wedge" tornado traversed the heavily populated Maryland suburbs of Washington, DC, at the height (5:00-5:30 PM EDT) of afternoon rush hour. As it crossed the main campus of the University of Maryland at College Park, the tornado killed two students and injured 54. This F3 tornado (referred here as the "College Park" tornado), though it only produced minimal damage to actual campus buildings, destroyed the facilities of the Maryland Fire and Rescue Institute co-located on campus, damaged or destroyed 200 vehicles, and did much tree damage (NOAA Storm Data 2001).

Earlier in the afternoon, another intense low-topped supercell thunderstorm spawned an F4 tornado in west central Virginia near the small town of Rixeyville, Virginia, in Culpeper County. This tornado, not discussed here, caused several injuries near Jeffersonton, Virginia, and produced significant damage (rated F2) to a number of buildings in Jeffersonton as it cut a 16 km path through Culpeper and Fauquier Counties in northern Virginia (NOAA Storm Data 2001)

These two supercell thunderstorms were the only two significant supercells on radar during the afternoon of September 24. They both produced strong to violent tornadoes during portions of their existence. However, several weak low-level (< 3 km in depth) circulations were observed on September 24, but they were short-lived and too shallow to produce any known tornado or wind damage. And, as is often the case during tornado episodes, moist sub-tropical and unstable air created conditions for flash flooding to occur. Six counties within the WFO Sterling County Warning Area (CWA) experienced flash flooding after the last tornado had dissipated around 2200 UTC.

This paper discusses two main themes: pre-storm convective assessment and radar signatures and perspectives. Salient radar characteristics from the College Park tornado will be discussed.

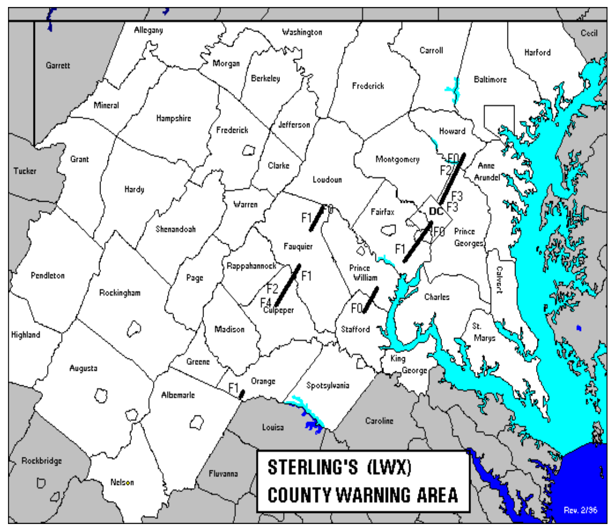

Fig. 1 - Regional view of mid-Atlantic depicting tornado tracks on 24 Sept 2001.

2. PRE-STORM CONVECTIVE ASSESSMENT

The synoptic setting for the September 24 tornado event was typical of many of severe events in the mid-Atlantic region. A fairly moist sub-tropical low-level boundary layer (with surface dew points of 18-22^{o} C) but relatively weak instability profiles (i.e., CAPE < 1200 J kg^{-1}; surface-based lifted index (LI) of 0 to -2) was combined with strong dynamics aloft (storm-relative helicity greater that 150 m^{2}/s^{-2}). At 1200 UTC 24 September 2001, at 500 hPa a deep (560 dm) cut-off extratropical low was located over Wisconsin with a central core temperature of -20^{o} C. Meanwhile, a strong upper level polar jet extended from southern Indiana northward across Lake Huron. At the surface, by 1200 UTC a warm front a moist southerly flow was established over the entire mid-Atlantic region ahead of a surface low pressure center located over northern Ohio. The1200 UTC

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sounding from Dulles, Virginia, (IAD) and modified with expected surface conditions at 2100 UTC on September 24 showed that with a modest forecast surface dry bulb temperature of 25°C and dew point of 21°C, the mean (lowest 150 hPa) CAPE was 1600 J kg^{-1}; surfaced-based LI was -5 and precipitable water was 40 mm. However, the morning helicity value was about 50 $m^2 s^{-2}$ yielding an energy-helicity (EHI) value of a modest 0.6.

At 1800 UTC 24 Sepember, the 500 hPa low was over the lower peninsula of Michigan, and at this level had a wind speed maximum on the east side of the low over southern Ontario of 35 m s^{-1}, and a 40 m s^{-1} jet core on the west side of the low. At 250 hPa, a strong polar 65 m s^{-1} jet streak extended from southern Ohio northeast into southern Quebec. At the surface, a low center was over northwest Pennsylvania at 1800 UTC with a trough of low pressure extending southward into western Virginia.

At 2100 UTC (shortly before the time of the F3 College Park tornado), the surface low had moved into central Pennsylvania with a surface trough axis extending along the lee of the Appalachians (approximately positioned along the Blue Ridge). Surface winds at DCA (Reagan National Airport) backed from 170 to 140 degrees between 1800 and 2100 UTC as the surface trough approached (and partially in response to the tornadic supercell located about 5 km away at 2100 UTC).

2.1 Methodology--BUFKIT sounding analysis tool

Anticipating convective potential and storm type requires knowledge of the atmospheric vertical structure and how it will evolve with time. Forecasters at WFO Sterling use a host of tools and methods to anticipate and assess the pre-storm convective potential and predict storm type. Traditional atmospheric sounding analysis of available observed radiosonde data is used.

In addition to the tools and observed data sets available for performing sounding analysis within the NWS AWIPS workstation, forecasters at Sterling supplement their AWIPS-based convective assessment routines with use of the “BUFKIT” sounding analysis tool (Mahoney and Nizol 1997).

As horizontal and vertical resolution of models continue to increase, forecasters here have found that the display of high resolution model data having mesoscale details requires higher temporal frequency of display grids. Until recently, the best resolution available on AWIPS was 3-hourly continuity in model grids. However, even 3-hour interval data are not sufficient temporally to resolve mesoscale details being created in high resolution mesoscale models (Waldstreicher et al. 1998).

Recently, forecasters at WFO Sterling have noticed forecast mesoscale details (10-100 km) that later appear consistent with observational data. The assessment techniques that most readily facilitate examination of such details are a combination of viewing various plan view AWIPS grids of the 3-hourly interval data combined with BUFKIT analyses of hourly model sounding data for selected stations. For convective analysis, where one must assess how a model is handling the vertical structure of momentum, temperature, and moisture, use of hourly model forecast soundings with BUFKIT provides a quick means to view virtually all of the model data (albeit at specific points) and thus assess the pre-storm convective potential.

For this event, forecasters noted consistently high values of helicity forecast around 2000-2300 UTC period on September 24 from the Eta model beginning with the model runs at 1200 UTC 23 September and continuing through 1200 UTC 24 September. Also, the model consistently forecast a low-level jet of 25 to 30 m s^{-1} between 1 and 2 km above the ground during this period over the region. Although forecast values of model CAPE where low (< 500) likely due to the convective parameterization scheme, the forecast wind field was conducive to supercells since helicity values were 300-350 m^2/s^{-2}.

3. RADAR PERSPECTIVES

Discussion here is based on radar data from the KLWX WSR-88D located at the WFO in Sterling, Virginia (near Dulles Airport-IAD). The KLWX 88D radar operated in volume coverage pattern (VCP) 11 (14 elevations scans every 5 minutes) throughout the duration of the events. Additional radar information for the College Park tornado was available from the Federal Aviation Administration’s Terminal Doppler Weather Radar (TDWR) located near Baltimore Washington International (BWI) airport. These data were available in real-time at WFO Sterling via a web link and have proven useful in evaluating storms as a supplement to existing NWS WSR-88D radar data (Vasiloff 2001). Radar images discussed below can be viewed via the WFO Sterling web site at:

http://www.nws.noaa.gov/er/lwx/Historic_Events/924tornadofiles/sep24.htm.

3.1 - College Park Tornado

The supercell that spawned the F3 tornado that struck College Park, Maryland, at 2118 UTC actually began in central Virginia. Earlier, around 1700 UTC, a small area of showers was observed on radar about 50 km southwest of Richmond, Virginia, or

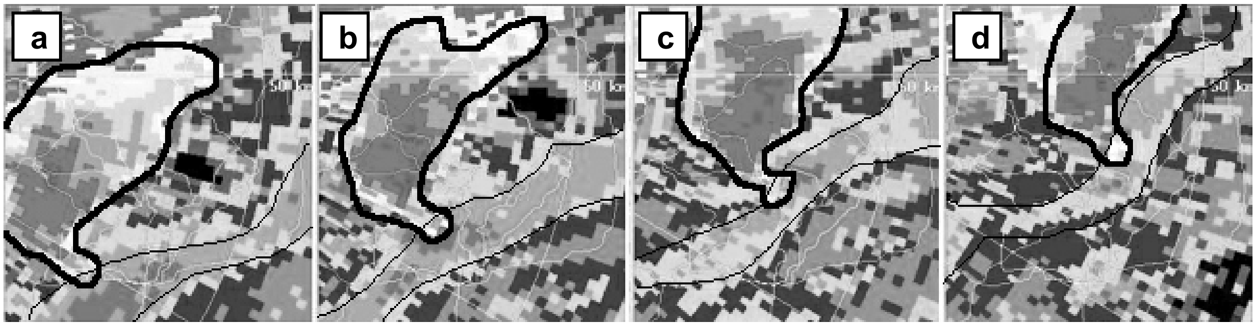

Fig. 2 - KLWX 0.5 degree base reflectivity time sequence; a) 2056, b) 2101, c) 2106, d) 2111 UTC; thick bold line outlines 40 dBz contour of supercell; thin line outlines shower boundary (beam height at center of image is 0.4 km located 103 degrees at 40 km).

about 200 km south-southwest of the KLWX 88D radar. As seen from KLWX, this area was comprised of four individual cells-all with reflectivities below 45 dBz. This area was moving north around 13 m s^{-1}. By 1800 UTC, the KLWX 88D radar began to detect subtle rotational features of two weak mesocyclones over central Goochland County, Virginia, (about 150 km from KLWX's 88D). These cells were separated a distance of about 8 km. At 1830 UTC, three small mesocyclones were over eastern Louisa County in Virginia. The strongest of these three appeared to be the northern-most cell. However, by 1900 UTC, the middle storm located on the Spotsylvania-Louisa county line became the dominate storm of the three.

Between 1900 and 1940 UTC, as the supercell traversed Spotsylvania County, Virginia, the radar data depicted the storm as having a 3-6 km wide circulation extending 2-4 km deep, and with rotation velocities ranging from 8 to 15 m s^{-1}. No known tornado or wind damage was reported with the storm as it traversed Spotsylvania County.

At 1945 UTC, the supercell had entered southern Stafford County, Virginia, and continued to track northeast at 12-14 m s^{-1}. Of interest at this time was the presence of an elongated east-west band of reflectivity roughly 2-5 km wide and about 25 to 50 km long trailing the supercell by 5 to 10 km.

As the cell moved northeast between 2000 and 2030 UTC over Stafford County, Virginia, it acquired various severe radar signatures (e.g., a bounded weak echo region (BWER); appendages on the southern flank; tight rotational couplet depicted in the doppler velocity data). Also at this time, two weaker supercells were to the northwest at roughly 7 and 13 km. At 2035 UTC, the storm had crossed into southern Fairfax County, Virginia, and had acquired a hook echo and associated BWER. It began to produce F1 (mainly tree) damage as it moved across central Fairfax County.

At 2043 UTC, as the storm is just south of Springfield, Virginia, 3-body scattering appeared in the radar data between 3 and 7 km in height, along with 65 dBz echoes aloft from 4 to 6 km. The velocity data above 3 km appears contaminated due this anomalous scatter. An appendage on the southern flank of the storm is evident at the 0.5 through 3.4 degree reflectivity scans. Velocity data show a more ill-defined low-level cyclonic circulation, with range-folded data obscuring details at the lowest elevation scan. At 2056 UTC, when the storm is just southwest of DC, a better-defined hook echo is evident in the 0.5 deg base reflectivity data.

At 2101 UTC, a few minutes after the storm had dropped an F0 tornado that crossed the southern edge of the Pentagon complex, the storm crosses the Potomac River into Washington, DC. The storm had a well-defined hook echo, but a broad circulation in the lowest velocity scans. The KLWX radar was located about 40 km due west from the center of the storm. Evident at this time is the narrowing distance, now only about 1 km, between the center of the 50 km-long shower band located to the south of the cell and the low-level circulation on the southern flank of the supercell (see Fig. 2).

At 2106 UTC, the shower band and the southern flank of the cell are beginning to interact. There is strengthening evident in the supercell's circulation between 0.5 and 3 km on the southern flank. There is also a BWER with a hook echo. At 3.3 degrees, a tight velocity couplet has a gate-to-gate (g2g) shear of 40 m s^{-1}.

On the next scan at 2111 UTC, the low level (0.5 degree) data showed the shower band fully interacting with the low-level storm circulation. The northern end of the shower band appears to deform and accelerate inward (northwestward) toward the inflow region of the supercell, while the portion of the shower band near the southern flank of the supercell appears to remain stationary, most likely because it is interacting with the rear flank downdraft (RFD) of the supercell. The lowest elevation slice from the KLWX 88D showed a developing and tightening circulation as well as a hook echo. At radar elevation scans above 1 km, the shower band appeared separate from the supercell (at a distance of about 1-2 km). Damage occurring just prior and at this time (2110 UTC) was limited to mainly F0 tree damage.

During this event, warning forecasters at WFO Sterling had access in real time to a limited set of radar data from the FAA TDWR located about 8 km south of Baltimore-Washington International (BWI) Airport in northern Anne Arundel County, Maryland. As pointed out by Vasiloff (2001), TDWR can supplement the 88D to identify and monitor tornadic vorticies. In this case, TDWR data were monitored closely to confirm the tornadic signatures from the 88D radar. In addition, the interaction of the shower band with the supercell that occurred at 2110 UTC was clearly shown in the TDWR data.

As the storm moved out of Washington, DC, into Prince Georges County, Maryland, (College Park is located in the northwest end of the county), the low-level circulation displayed a classic tornadic vortex signature (TVS) at the lowest two radar elevation scans. The g2g velocity couplet at 0.5 degrees measured 30 m s^{-1} of shear while at 1.5 degree the g2g shear was 48 m s^{-1}. At the surface, an impressive large wedge-shaped tornado quickly developed in less than 5 minutes and moved across the University of Maryland campus at College Park. At 2121 UTC, the storm exhibited some of the highest g2g shears for the entire life the supercell, with 45.5 m s^{-1} at 0.5 degrees and 53.5 m s^{-1} at 1.5.

Radar continued to show a TVS for the next 20 minutes. At 2126 UTC, the low-level g2g shear at 0.5 degrees is an impressive 58 m s^{-1}. Later, at 2136 UTC, the tornado struck Laurel High School, inflicting strong F2 damage. The g2g shear at this time was still 50 m s^{-1} at 1.5 degrees (37 m s^{-1} at 0.5 degrees). Five minutes later, at 2142 UTC, the tornado moved into southern Howard County in central Maryland. While signatures were still strong as the tornado moved into Howard County, they quickly began to weaken. On the next radar scan (2151 UTC), what remained was a remnant weak low-level circulation (17 m s^{-1} rotation velocity for a 3-4 km diameter mesocyclone) located in east-central Howard County (60 km northeast of KLWX). By 2156 UTC, only a shallow, weak low-level circulation remained.

Extrapolation of the College Park tornado track brought it close to Baltimore City. In this event, the TDWR was located somewhat closer to the College Park tornadic supercell then the 88D (35 km vs 45 km). As the supercell moved northeast and away from the 88D, it actually moved closer to the TDWR. At 2150 UTC, when a warning decision for Baltimore City and Baltimore County was being considered, data from the closer (20-30 km) TDWR helped supplement the weakening trend evident from the more distant (60-70 km) KLWX 88D radar. It was then decided that a tornado warning was not required as the storm had drastically decreased in intensity. Thus, TDWR data aided in the warning decision process to not issue a tornado warning for Baltimore. The tornado's parent mesocyclone weakened over the western suburbs of Baltimore City. No tornado or wind damage was reported in either Baltimore County, Maryland, or Baltimore City during this event.

4. SUMMARY

This paper detailed the evolution of the supercell that produced the deadly College Park F3 tornado. Conditions on 24 September 2001 were conducive for formation of tornadoes based upon upper air analysis of forecast model parameters. From an anticipation of severe weather, forecasters at WFO Sterling were able to issue timely tornado warnings to the public during the event.

There appeared to be evidence that a narrow band of showers interacted with the supercell low-level circulation and allowed the rapid formation of the F3 College Park tornado. Although forecasters did not know exactly what would happen during this interaction, it heightened awareness of the situation, and tornado warnings were issued 20 minutes before the interaction occurred. It appears the interaction of the between the trailing band of showers and the supercell's low-level circulation helped transform a tornado that had been limited to F0-F1 damage, into a strong and deadly F3 tornado. Importantly, this rapid spin-up to a strong wedge F3 tornado from a weak F0 occurred in less 5 minutes.

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