P1.27 A RARE TORNADIC THUNDERSTORM IN NORTHEAST UTAH

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I. Introduction

Tornadic thunderstorms occur in regular frequency over the Central Plains of the United States during the spring and summer months. The reported number of tornadic thunderstorms drops rapidly as one moves west of the High Plains, partly based on the sparsely populated regions of the western United States. Previous studies have indicated that tornadic thunderstorms can and do occur over the Rocky Mountains (Fujita 1989, Evans and Johns 1995) and that the frequency of reported tornadoes continues to rise as population density and public awareness increases. The recent Salt Lake City Tornado in August 1999 was one well documented example of the potential for tornadoes west of the High Plains. The deployment of the National Weather Service Doppler Radar (WSR-88D) in the mid-1990's over the western United States, has enabled forecasters to better interrogate local severe thunderstorms. However, limitations exist with many radars located at high elevations across this region. The limitations present a unique challenge to forecasters as they deal with issues such as beam blockage and overshooting due to the complex terrain. This is especially true at the Weather Forecast Office (WFO) in Grand Junction, Colorado where the WSR-88D (KGJX) is located on top of Grand Mesa in western Colorado at an elevation of 3050 m MSL.

On 3 September 1999, an isolated severe thunderstorm tracked northeast across the Uinta Basin of northeast Utah. The Uinta Basin is surrounded by higher terrain in all directions and is located approximately 180 km northwest of KGJX (Fig. 1). Typically, storms tend to dissipate as they move off the higher terrain surrounding the Unita Basin; however, on this occasion the thunderstorm moving off the higher terrain intensified. The storm eventually produced hail up to the size of golf balls and an F1 tornado. This tornadic thunderstorm was located over 185 km from KGJX. Due to the distance from the radar only two beam slices intersected the storm: the 0.5° and the 1.5° slices. The lack of sufficient radar data can prevent the forecaster from obtaining a true measure of the rotational depth in any given storm, thus reducing the likelihood of correctly identifying a tornadic thunderstorm beyond 100 km from the radar. A brief overview of the local storm environment as it pertains to the Naples, Utah tornado will precede a detailed discussion of radar performance and coverage exhibited by the KGJX WSR-88D radar during this tornadic thunderstorm.

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II. Synoptic and Mesoscale Environment

Evans and Johns (1996) observed synoptic scale upper-level wind flow patterns conducive for producing tornadoes in the Bighorn Mountains of Wyoming. Their research found that southwest flow was most favorable for tornadic thunderstorm generation over northern Wyoming. Similarly, the synoptic pattern of 1200 UTC 3 September 1999 exhibited southwest flow across most of Utah in response to a 500 hPa closed low over northern Utah. Between 1200 UTC 3 September and 0000 UTC 4 September the 500 hPa low ejected northeast into western Wyoming. In association with this feature, a 250 hPa jet maximum of 35-45 ms^{-1} had nosed into northeast Utah by 0000 UTC 4 September. This placed Naples/Vernal under the left exit region of the jet maximum.

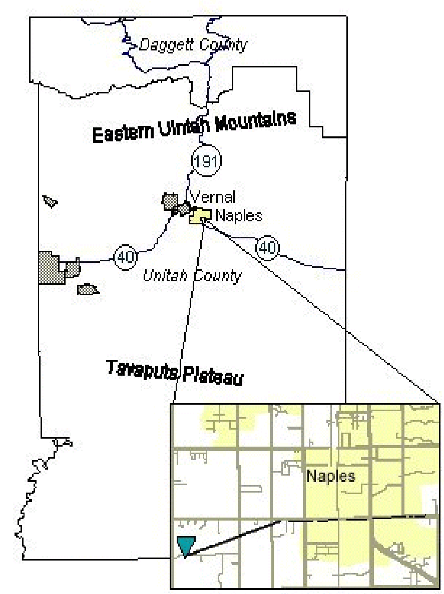

Fig. 1. Map of northeast Utah with inlay showing path of tornado across Naples, Utah.

The upper-air site most representative of the expected conditions across northeast Utah during the afternoon of 3 September 1999 was Salt Lake City (KSLC). Both the 1200 UTC 3 September and 0000 UTC 4 September KSLC soundings were utilized to interrogate the mesoscale environment. The morning sounding from KSLC showed a marginally unstable atmosphere with a lifted index (LI) of -2°C and convective available potential energy (CAPE) of 352 Jkg^{-1}. Directional shear was negligible as uniform southwest flow was present through 200 hPa. Speed shear in the lowest 6 km was 22 ms^{-1}. A modified LI of -3°C and CAPE of 599 Jkg^{-1} were obtained by adjusting the 1200 UTC KSLC sounding using the observed 2100 UTC temperature and dew point at the Vernal Airport (approximately 2 km northeast of the tornado path). An examination of the evening KSLC sounding showed that cooling of 2°C to 4°C occurred at 500 hPa, a likely result of the eastward progression of the 500 hPa trough. Overall, the thermodynamic profile displayed little change with an observed 0000 UTC LI of -4°C and CAPE of 329 Jkg^{-1}. However, significant differences were observed in the wind data. Winds in the 0 to 6 km layer increased and veered to the west, and speed shear within this same layer increased to approximately 33 ms^{-1}. A comparison of the 1200 UTC 3 September and 0000 UTC 4 September 1999 soundings showed that 300 hPa winds had accelerated from 30 ms^{-1} to 45 ms^{-1}.

IV. Storm Evolution

The severe thunderstorm was initially detected around 2045 UTC 3 September 1999 near Roosevelt, UT or approximately 200 km from the KGJX WSR-88D. The next adjacent radar available for the forecasters is the Salt Lake City WSR-88D (KMTX) which is located on the west side of the Wasatch Mountains. However, due to beam blockage and overshooting due to the large distance to the storm, little information was available for forecaster interrogation of this storm from this radar.

Surface reports received from Roosevelt, UT indicated heavy rain and gusty winds were occurring with the passage of the thunderstorm. This report prompted the issuance of a Short Term Forecast (NOW) by the forecast staff at WFO GJT as the thunderstorm was moving northeast into the Uinta Basin. Around 2109 UTC, the cell began moving off the higher terrain to the southwest of Naples/Vernal, Utah. With the storm moving into the WFO GJT county warning area (CWA), better reflectivity indicators were showing up on the KGJX Principal Users Position (PUP) workstation. Initial indications showed a strengthening storm moving into the Uinta Basin. With several thunderstorms present on the KGJX radar screen, cells in closer proximity to the radar appeared to be stronger as the KGJX WSR-88D was able to sample a broader depth of these individual cells. Thunderstorms on the outer edge of the radar, such as the storm entering the Uinta basin, were only being intersected by the 0.5° and 1.5° elevations angles. This provided minimal data for the forecasters to work with as the KGJX WSR-88D was sampling only the middle and upper levels of the storm (Fig. 2).

As thunderstorms closer to the radar site continued to trigger audible alerts associated with the PUP workstation, the Uinta Basin thunderstorm showed little change in strength through 2129 UTC; however it

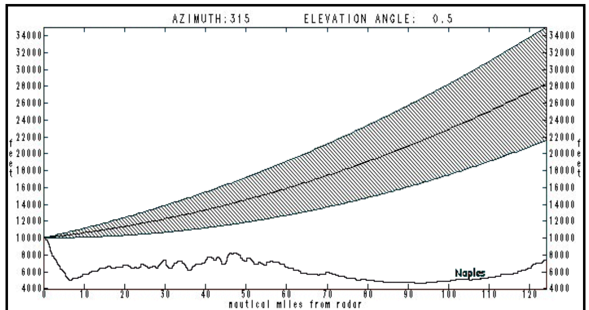

Fig. 2. Cross-section view of the 0.5° radar beam looking from the KGJX WSR-88D on top of Grand Mesa northwest to Naples, Utah. The median point of the radar beam under normal refractive conditions would have been 8534 m MSL or roughly 7315 m above the Uinta Basin floor.

did maintain the same intensity as it moved across the basin. The 2129 UTC scan triggered the mesocyclone algorithm, setting off an audible alarm at the PUP workstation. This action prompted the issuance of a severe thunderstorm warning by the forecast staff in Grand Junction; however, post-event public reports indicated that the tornado had already lifted off the ground by this time. The triggering of the audible alarm coincided well with the time at which the KGJX WSR-88D began to receive information from the 2.4° elevation angle. By the next volume scan, the thunderstorm had begun to accelerate to the northeast and eventually moved into northwest Colorado before weakening and eventually dissipating. There were no reports of severe weather occurring with this thunderstorm after 2130 UTC.

Post-event evaluation of the KGJX WSR-88D data showed several factors that may have aided the forecasters in determining the overall potential of this tornadic thunderstorm. Close examination of the 0.5°, 1.5°, and 2.4° elevation scans were performed on reflectivity, velocity and storm relative velocity map (SRM), and vertical integrated liquid (VIL). The 2.4° elevation scan provided very little useful data as the beam was overshooting the storm at this point.

The tornadic thunderstorm was initially identified as a cell by the KGJX WSR-88D at 2053 UTC 3 September 1999. Maximum reflectivity displayed by the radar was around 50 dBZ, although the depth of the 50 dBZ core was estimated to extend from the base of the storm to 5500 m above ground level (AGL). Reflectivity trends over the next 30 minutes showed little change in storm intensity; however cell based VIL rose from around 18 kgm^{-2} to 35 kgm^{-2} (2129 UTC). Reflectivity time lapse indicators showed the storm made a definitive turn toward the right of the mean flow at approximately 2117 UTC 3 September 1999.

The SRM products from 2117 UTC through 2136 UTC were examined to determine the strength and depth of any rotational velocity present within this

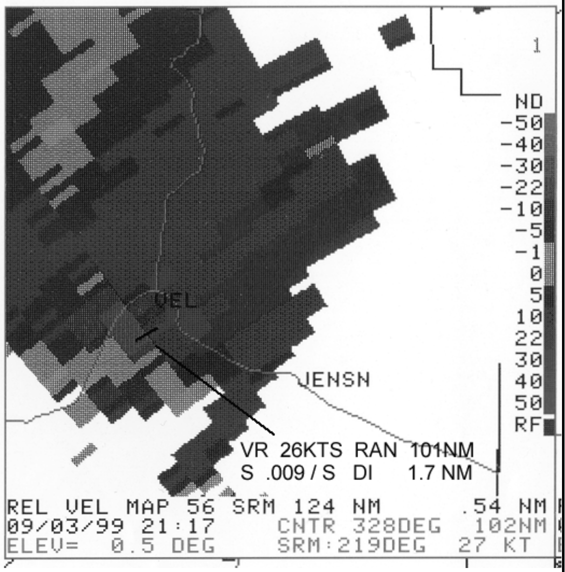

Fig. 3. 2117 UTC 3 September 1999 Storm Relative Velocity Map (SRM).

thunderstorm. At 2117 UTC, the 0.5° SRM product was closely scrutinized by performing VR/Shear calculations of velocity couplets within the product. A broad area of circulation was noted in the product with the higher velocity values present as gate-to-gate shear (Fig. 3). Performing the VR/Shear calculation on this couplet revealed rotational shear of 13 ms^{-1} across a diameter of 3.15 km (1.7 nm) at a distance of 187 km (101 nm) from the radar. Interrogation of the 1.5° SRM product indicated storm top divergence present. With the discovery of this rotation within the storm, and after reviewing additional SRM products, base velocity data, and time lapse imagery of the cell, it was determined that the thunderstorm exhibited characteristics similar to a mini-supercell (Green et al. 1996; Grant and Prentice 1996; Burgess et al. 1995). After determining that the storm was indeed rotating, the rotational shear

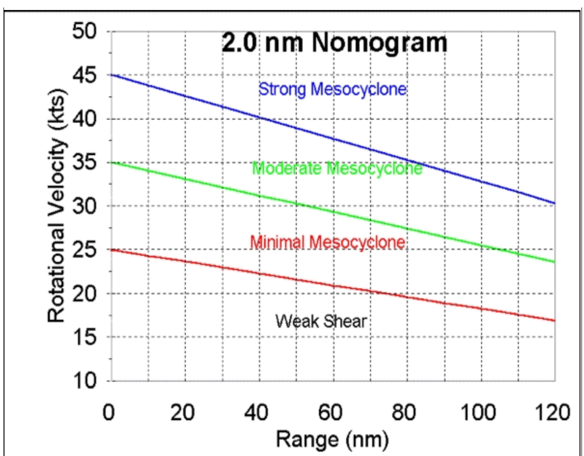

Fig. 4. 2.0 nm Nomogram depicting potential Mesocyclone strength based on rotational velocity and distance from radar.

discovered in the 2117 UTC volume scan was compared to the 2.0 nm nomogram (Fig. 4) developed by the Operational Support Facility (OSF) for determining mesocyclone strength in supercell thunderstorms. The rotation present in this storm was indicative of that associated with a low-end moderate mesocyclone. A check of the 1.0 nm nomogram put this cell in the strong category. Since this storm was determined to have a diameter of 3.15 km (1.7 nm), a valid argument can be made that his particular storm was representative of a moderate mesocyclone (Public reports confirmed that the tornado was already on the ground at this point). It is important to note that the approximate elevation of the rotation detected by the radar was over 7315 m above ground level (AGL) due to standard beam refraction and the distance from the radar site. Thus making it difficult to approximate the actual depth of rotation within the cell.

By 2123 UTC the rotation in the 0.5° SRM product had increased to 16 ms^{-1} at 189 km (102 nm)

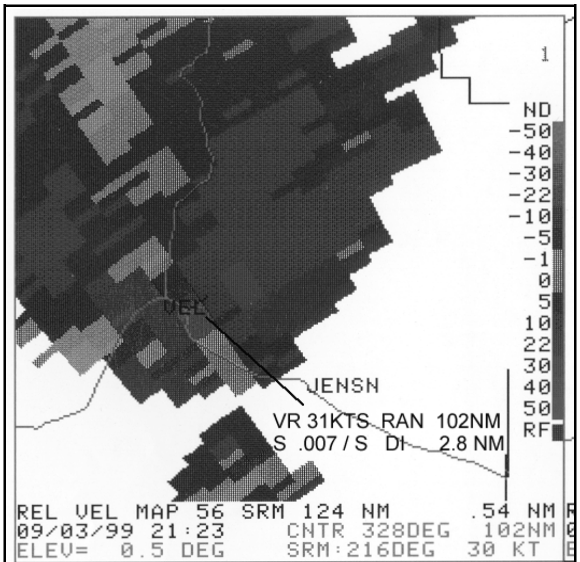

Fig. 5. 2123 UTC 3 September 1999 Storm Relative Velocity Map (SRM).

with a diameter now measuring 5.19 km (2.8 nm) (FIG 5). The rotational speed had strengthened, but gate-to-gate shear was no longer present. This roughly approximated the time that the tornado was reported to be dissipating by the general public. A study conducted by Kruzdlo II (1998) showed a correlation between thunderstorms producing tornadoes over the San Joaquin Valley of California coinciding with weak to moderate mesocyclones exhibiting gate-to-gate rotational shear. The strength of the mesocyclones were determined by using the 1.0 or 2.0 nm nomograms. Similar strength mesocyclones which did not indicate gate-to-gate shear failed to produce a tornado in that study. This case appears to follow this finding in that the tornado began to dissipate as the tight gate-to-gate shear dissipated.

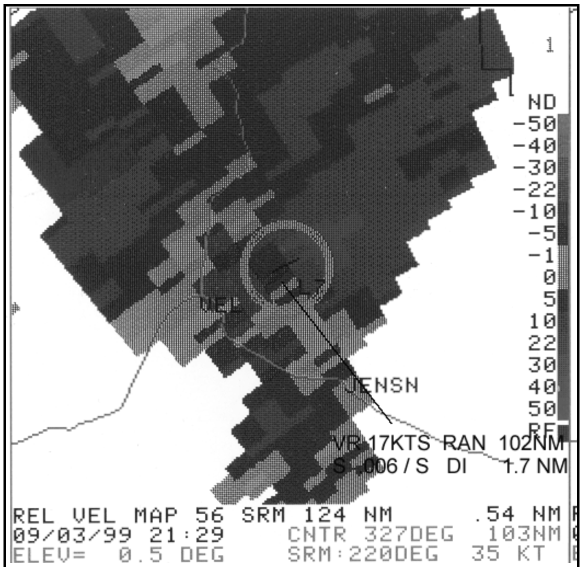

Fig. 6. 2129 UTC 3 September 1999 Storm Relative Velocity Map (SRM). Radar detected Mesocyclone denoted by circle shape within velocity signatures.

As previously discussed, the 2129 UTC scan triggered the mesocyclone algorithm; however the VR/Shear profile (Fig. 6) of the storm at this point, showed that the rotational velocity had decreased to around 9 ms^{-1} at a distance of 189 km (102 nm) from the radar. By this time, the thunderstorm had already produced a tornado along with large hail. By 2136 UTC, the storm exhibited even less rotational values and at this point, no further interrogation of the storm was conducted.

V. Damage

The tornado traveled in a southwest to northeast direction across the city of Naples, Utah. The damage path covered nearly 7 km with an average width of 35 m. A newly-built garage in the southwest portion of the town was destroyed, and several trees along the path of the tornado were uprooted. The roofs of several buildings were damaged by felled trees. Damage amounts were estimated at $700,000. One injury occurred as the result of flying debris.

VI. Conclusions

An F1 tornado caused considerable damage to portions of Naples, Utah on 3 September 1999. The location of the KGJX WSR-88D radar on top of Grand Mesa in western Colorado (3050 M) resulted in limited radar coverage of this tornadic thunderstorm. Forecasters will need to exercise caution when working with high elevation radars due to the limited number of elevation scans which will be available for storm interrogation. Future studies will need to be conducted, especially those regarding the use of alternative VCP's which will allow for lower slices beyond the traditional VCP-11 and VCP-21 scanning schemes. Modifying the volume coverage patterns at high elevation radars, will enable forecasters to better "see" into a storm, and will lead to better detection of severe weather. Furthermore, an acute awareness of the local storm environment and how it may or may not be affected by local topographical features in the mesoscale or microscale environments will result in a better understanding of how local storms behave in regions with complex terrain.

VII. Acknowledgements.

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