P1.2 THE 10-11 APRIL 2001 LATE NIGHT TORNADO OUTBREAK ALONG A SQUALL LINE IN SOUTH CENTRAL NEBRASKA/NORTH CENTRAL KANSAS

Rick Ewald*
National Weather Service, Hastings, Nebraska

Daniel D. Nietfeld
National Weather Service, Omaha/Valley, Nebraska

1. INTRODUCTION

The occurrence of tornado outbreaks associated with the bowing segment of a convective squall line over parts of the Mississippi and Ohio River valleys has been well documented in the recent years (DeWald and Funk 2000, Funk et al. 1999, Schmocker et al. 1998). Johns (1993) described the "dynamic" synoptic pattern associated with bow echoes, which is usually prevalent during the cool season and is most common over the lower Mississippi Valley and southeastern states. On 10-11 April 2001, such a system formed in the high plains region of western Kansas, and moved northeast, traveling several hundred miles. In the eight plus years the NWS Hastings, Nebraska (KUEX) WSR-88D has been in operation, the authors have noticed these types of events may not occur as frequently in the Hastings county warning area (GID CWA) as they do further southeast.

This study looks at the line of storms as it moved across the GID CWA. The importance of the synoptic and storm environment is considered. KUEX radar data is examined, with a particular emphasis placed on the large tornado outbreak as the line passed through the GID CWA. The tornadic storms that formed and moved across Smith and Osborne counties in Kansas were representative of how most of the storms evolved during the event and these are investigated in detail.

2. SYNOPTIC AND MESOSCALE ENVIRONMENT

There were several important synoptic and mesoscale atmospheric features present in the central and high plains on 10-11 April 2001 (not shown). The thunderstorms began moving into the GID CWA around 0300 UTC 11 April. At that time a 500 mb low pressure center was over northern New Mexico and a surface low pressure center was located over southwest Kansas. From the surface low, a quasi-stationary front extended northeast through the GID CWA and into eastern Nebraska. The thunderstorms moved along and just north of this frontal boundary, with the storm motion being parallel to the alignment of the front. Strong gradient winds were present to the south of the front, with 850 mb winds of 25 m s^{-1} observed on regional profilers, and surface winds gusting as high as 20 m s^{-1} at Great Bend, Kansas (GBD) at 0400 UTC. These strong winds were advecting higher equivalent potential temperature values into the frontal zone, resulting in surface-based convective available potential energy (CAPE) values exceeding 2500 J kg^{-1} 100 km south of the front near GBD. In addition, persistent vertical motion resulted in the formation of stratus clouds along and north of the front, with visibilities observed below one-quarter mile, and cloud bases from zero to a few hundred meters. South of the front, the low level winds veered with height and increased in speed, with representative hodographs showing 0-3 km storm-relative helicity (SRH) values exceeding 300 m^2 s^{-2} at 0300 UTC. It is important to note that surface winds 5 to 20 km north of the front were from the east or southeast, yielding a higher value of the 0-1 km SRH.

Recent research stemming from the Verification of Rotation in Tornadoes experiement (VORTEX) has pointed to three key ingredients necessary for tornado formation: a persistent, rotating updraft; enhanced SRH along or just north of a boundary; and a warm and buoyant rear-flank downdraft (RFD) (Browning 2002). The instability and shear present in the atmosphere the evening of 10 April 2001 supported persistent, rotating updrafts within many of the storms. It is hypothesized that the surface frontal structure may have provided the enhanced SRH as the storms moved along and just north of the boundary, which is consistent with findings from VORTEX-95 (Markowski et al. 1998). The presence of fog and stratus implied very low lifted condensation level (LCL) heights, approximately 100 meters or less, which is consistent with findings from Rasmussen (1998) when distinguishing between tornadic and non-tornadic supercells. With the low LCL heights, low surface dewpoint-depressions were common. RFD buoyancy might be at least partially inferred based on observations of surface-based dewpoint depressions (Browning, 2002), with low dewpoint depressions correlating with relatively warmer, more buoyant RFD characteristics.

3. SQUALL LINE EVOLUTION

In the early evening of 10 April, a squall line formed from southwest Kansas to the Texas panhandle and proceeded to move northeast at 20 to 25 m s^{-1}. The line reached southeast Nebraska/northeast Kansas after midnight on 11 April. Throughout the event, damaging winds, hail and tornadoes were reported. The storm fit the criteria of a derecho as set forth by Johns and Hirt (1987).

As the squall line progressed toward the GID CWA, it exhibited symmetric MCS characteristics (Houze et al. 1989), with a sharp reflectivity gradient along the leading edge, a trailing region of stratiform precipitation resulting from storm relative front to rear flow, and intense pulses of rear to front flow. Storm-relative velocity data from the Dodge City and Goodland Kansas radars (not

* Corresponding author address: Rick Ewald, National Weather Service, 6365 North Osborne Drive, Hastings, NE 68901; email: rick.ewald@noaa.gov

shown) both indicated mid-altitude radial convergence (MARC; Schmocker et al. 1996) of 20-30 m s^{-1} from 3-5 km. This may have contributed to the northern end of the line bowing just as it was entering the southwest section of the GID CWA. The bow echo (Fujita, 1978) persisted as the storms moved through the GID CWA. From the KUEX radar data, it appeared that the part of the line south of the bow apex moved slightly faster than the area north of the apex. Thus while the entire line moved in a northeast direction, the apex seemed to propagate southward along the line.

Twelve tornadoes were produced or moved into the GID CWA during a three-hour period (Figure 1). Four were rated F1 while the other eight were rated F0. They all developed along or just north of the frontal boundary. Approximately half the tornadoes formed 5-15 km northwest of the bow apex within a well-defined circulation. Similar results have been noted by Przybylinski and Schmocker (1993) and Funk et al. (1996). The other half formed along the leading edge of the storm, directly on the apex of the bow as described in Schmocker et al. (1998). On occasion, several tornadoes occurred simultaneously. Additional tornadoes developed to the east and south after the derecho moved out of the GID CWA. A few wind damage reports were received throughout the CWA with speeds recorded up to 40 m s^{-1}. However the number of damage reports due to straight-line winds was not as prevalent as in many derecho events.

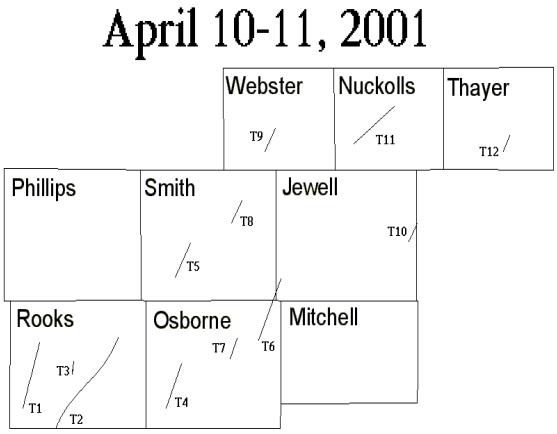

Figure 1: Location of tornadoes in the Hastings NE CWA.

4. SMITH COUNTY TORNADOES

The squall line had produced four tornadoes in the GID CWA by the time it was entering Smith county. The circulation associated with the comma head section of the bow echo that produced the first tornado (T1) was still intact although the tornado had dissipated in the central part of Rooks county.

The rotational velocity (V*r*) decreased to 16 m s^{-1} at 0515 UTC after T1 dissipated. Between 0520 and 0524 UTC, V*r* increased to 23 m s^{-1} (Vr max in lowest four elevation angles was used). During this same time, a pronounced rear inflow notch (RIN) could be seen on the 0.5° base reflectivity product (Figure 2). Tornado #5 (T5) occurred at 0524 UTC just west (left) of

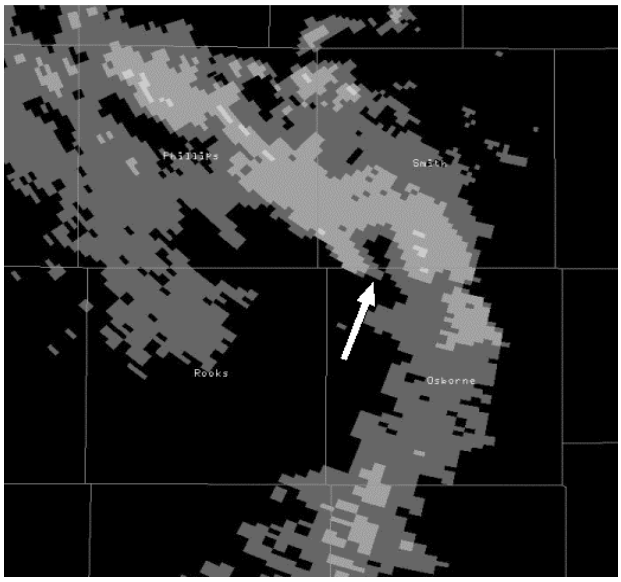

Figure 2. WSR-88D reflectivity image at 0.5° elevation angle at 0524 UTC . Black areas depict values < 35 dBZ. Shaded areas depict contours increasing by 10 dBZ. White arrow points to rear inflow notch.

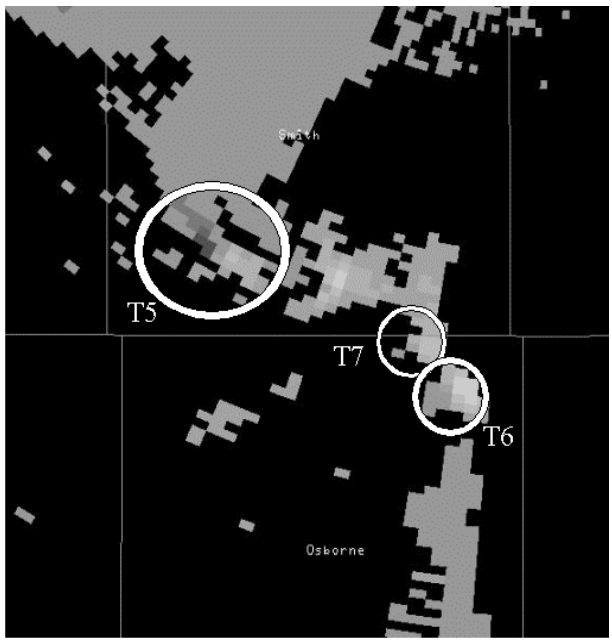

Figure 3. WSR-88D storm relative velocity image at 0.5° elevation at 0529 UTC. Circles depict circulations associated with 3 tornadoes (T5, T6 & T7). Maximum rotational velocities for
T5 > 28 m s^{-1}; T6 = 13 m s^{-1}; T7 > 18 m s^{-1}.

the RIN while the V*r* was strengthening (V*r* > 28 m s^{-1} at 0529 UTC. Figure 3). T5 remained on the ground for 11 minutes and traveled 7 km before dissipating at 0535 UTC. It was rated F1 and produced $75000 of damage.

Between 0535 and 0544 UTC the meso-vortex remained in tact although V*r* decreased to 18 m s^{-1}. During this time the RIN also became less pronounced. By 0549 UTC the RIN was once again strengthening (Figure 4), and even appeared to fully penetrate the reflectivity line (at 1.5° and 2.4° not shown here) while V*r* increased to 23 m s^{-1} (Figure 5). Tornado #8 (T8) touched down at 0549 UTC. T8 traveled just over 6 km in 6 minutes and was rated F0.

In addition to the aforementioned tornadoes, similar trends were found in T9 and T11 and to a lesser extent T1 and T12 where the RIN and V*r* strengthened,

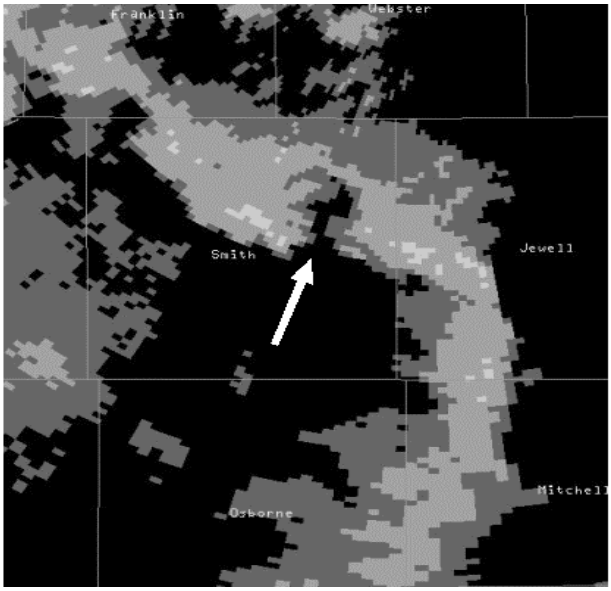

Figure 4. Same as Figure 2 except at 0549 UTC.

just before the tornado touched down.

5. OSBORNE COUNTY TORNADOES

The first tornado (T4) in Osborne county occurred at 0505 UTC. This tornado formed at the leading edge of the bow echo, in a region with a very tight reflectivity gradient. The V*r* increased from 18 to 21 m s^{-1} at the lowest three elevation angles as the tornado touched down. T4 was rated F1 and covered a path of 15 km in 15 minutes. T4 dissipated at 0520 UTC as the circulation broadened and weakened somewhat. Funk et al. (1999) described a similar case where the circulation propagated rearward with respect to the apex as it weakened.

Shortly after T4 dissipated, tornadoes 6 and 7 (T6 & T7) developed along the leading edge of the storm at the apex. T6 and T7 touched down at approximately the same time, 0524 UTC, within 6 km of each other. Both were rated F1. T6 had a path length of 21 km over a 14 minute period, while T7 lasted 5 minutes and covered 3 km. V*r* for both increased to 23 m s^{-1} at 0524 UTC. T6 maintained a respectable circulation over the next 20

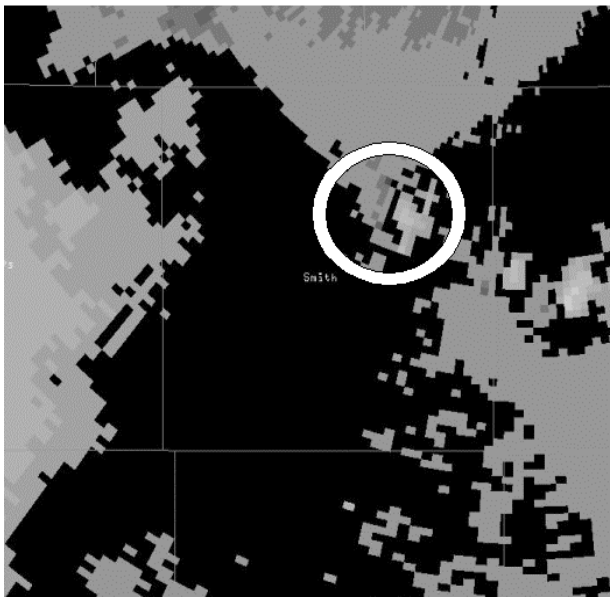

Figure 5. Same as Figure 3 except at 0549 UTC. Maximum rotational velocity for area in circle = 23 m s^{-1}

minutes while T7 slowly weakened. Both circulations followed a similar transition as that of T4 as they propagated rearward with respect to the apex. The circulation associated with T6 maintained itself and eventually spawned another tornado (T11) in Nuckolls county Nebraska.

While many of the circulations met mesocyclone criteria, (Burgess et al. 1993), very few were strong enough to trigger the build 10 tornadic detection algorithm (TDA) alarm on the KUEX WSR-88D. This was especially true for those that occurred along the leading edge such as the Osborne county storms. These storms also showed little in the way of base reflectivity signatures that would lead one to believe a tornado was occurring. Herald and Drozd (2001) found utility in using spectrum width and combined shear parameters in determining tornadic potential in storms where traditional radar signatures (i.e. base reflectivity and storm relative velocity) may not clearly direct one towards the issuance of a tornado warning. They found spectrum width values of 8 ms^{-1} or greater, plus combined shear of 0.0090 s^{-1} or higher, were beneficial indicators of tornadic circulations. As T6 and T7 formed, the spectrum width exceeded 8 m s^{-1} while combined shear values were in excess of 0.0100 s^{-1}.

When comparing the Osborne county tornadoes with others during the event, similar trends were found with T2, T3, T4, T6, and T7 as all formed at the leading edge on the apex.

6. SUMMARY

Twelve tornadoes were generated across the GID CWA as a derecho traversed parts of the high and central great plains on 10-11 April 2001. Environmental conditions were favorable for tornadic development with a surface front draped across the southern part of the CWA, moist unstable air in the vicinity of the boundary,

low LCL heights, and adequate wind shear.

Approximately half of the tornadoes formed along the leading edge at the apex. Several of the mesocyclones held together after tornado dissipation, propagated rearward (northwest of the apex), and lead to additional tornado formation as the line progressed. The other half of the tornado events, including those in Smith county, developed in the comma head region to the northwest of the apex. Tornadogenesis appeared to coincide with the RIN punching into, and at times through, the line of storms. There also appeared to be a correlation between the RIN filling, and the associated tornado dissipating.

Recognizing and reacting properly to events that are relatively uncommon in a particular region of the country can pose a challenge to any meteorologist. The NWS has recently purchased the Weather Event Simulator for the field offices to help meet this challenge. Prior to the 2002 convective weather season, many NWS meteorologists (all of those at NWS Hastings and Omaha Nebraska) went through a simulated training exercise on the April 10-11, 2001 severe weather event.

7. ACKNOWLEDGEMENTS

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