A CASE STUDY OF A WELL-DEFINED BOW ECHO WITH BOOKEND VORTICES

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Abstract

An analysis of a bow-echo event with associated bookend vortices is presented. The evolution of the cell is followed from a weak thunderstorm in north Alabama to a well-defined bow echo which caused widespread damage in middle Tennessee. The presence of bookend vortices is shown and is linked to the tornadic damage found in areas east of Nashville. The synoptic situation along with the bookend vortices is a condition often associated with the development of non-supercellular tornadoes. Study findings can be used by forecasters to aid in the warning of tornadoes in similar events in the future.

1. Introduction

Early on the morning of 9 June 1996, a thunderstorm moving through middle Tennessee developed rapidly into a well-defined bow echo (Fujita 1981). The storm eventually caused widespread damage in Wilson County, just east of Nashville. Although most of the damage that occurred was the result of "straight-line" winds near the apex of the bow, there were eyewitness accounts of funnel clouds and short-lived tornadoes. A post-storm survey conducted by local emergency management and National Weather Service personnel revealed small areas of F0 to F1 (Fujita 1981) tornado damage embedded within the widespread straight-line wind damage.

As the bow evolved, WSR-88D storm-relative velocity products revealed weak rotation at both ends of the bow—one end rotating cyclonically and the other anticyclonically. Furthermore, significant wind shear was also noted near the apex. It is hypothesized that the tornadic damage observed during the post-storm survey was the result of brief gustnadoes/tornadoes associated with the cyclonically rotating "bookend" vortex at the western edge of the bow echo, and/or with the area of strong shear near the bow's apex. Radar characteristics of the bow echo will be discussed, as well as the wind damage associated with these radar characteristics.

2. Synoptic/Mesoscale Environment

The 0000 UTC 9 June 1996 upper-air analysis (not shown) showed a relatively deep 850-mb to 500-mb closed low near the Mississippi River between Memphis, Tennessee and Paducah, Kentucky. This resulted in a generally southerly wind, gradually increasing in speed with height, through the lowest 500 mb across middle Tennessee. The 0000 UTC Nashville sounding (not shown) indicated only marginal instability and weak vertical wind shear. Surface dewpoints were in the low to mid 60s (F) across the area. However, manual surface analyses from 0400 UTC, 0800 UTC, and 1200 UTC 9 June 1996 (Figs. 1, 2 and 3) showed a wave of low pressure moving across middle Tennessee along a frontal boundary. This boundary/low pressure wave served as a focusing mechanism, aiding the development of a lone thunderstorm in northern Alabama along the frontal boundary just ahead of the low pressure wave. As the storm moved into middle Tennessee, it rapidly intensified and developed into a well-defined bow echo. This rapid intensification, along with the presence of a surface boundary, weak vertical wind shear, and small-scale cyclonic rotation at the end of the bow echo, are the four main ingredients often associated with the formation of non-supercellular tornadoes (Lee and Wilhelmson 1996).

3. Radar Characteristics and Damage

Initially, as the thunderstorm moved out of north Alabama, the WSR-88D showed the storm to be quite benign, with reflectivity values in the 30-40 dBZ range and vertically integrated liquid (VIL) values of only 5-10 kg m^{-2}. However, the Rapid Update Cycle (RUC) surface analyses (on PC-GRIDDS) revealed the boundary (mentioned previously) lying across middle Tennessee with the associated wave of low pressure providing an area of enhanced lift favorable for thunderstorm development and intensification. Indeed, at around 0710 UTC, VIL values associated with the thunderstorm began to increase; additionally, the composite reflectivity showed a 55-60 dBZ core aloft and the beginnings of the bow-echo structure. The 0.5° elevation base reflectivity, however, remained quite weak. Forecasters realized at this time that the thunderstorm was intensifying significantly, as the strengthening updraft suspended a core of rain aloft. Additionally, a reflectivity cross section was cut through the developing storm, further revealing the suspended reflectivity core. The cross section showed a layer between 10 and 20 thousand feet containing reflectivity values greater than 50 dBZ.

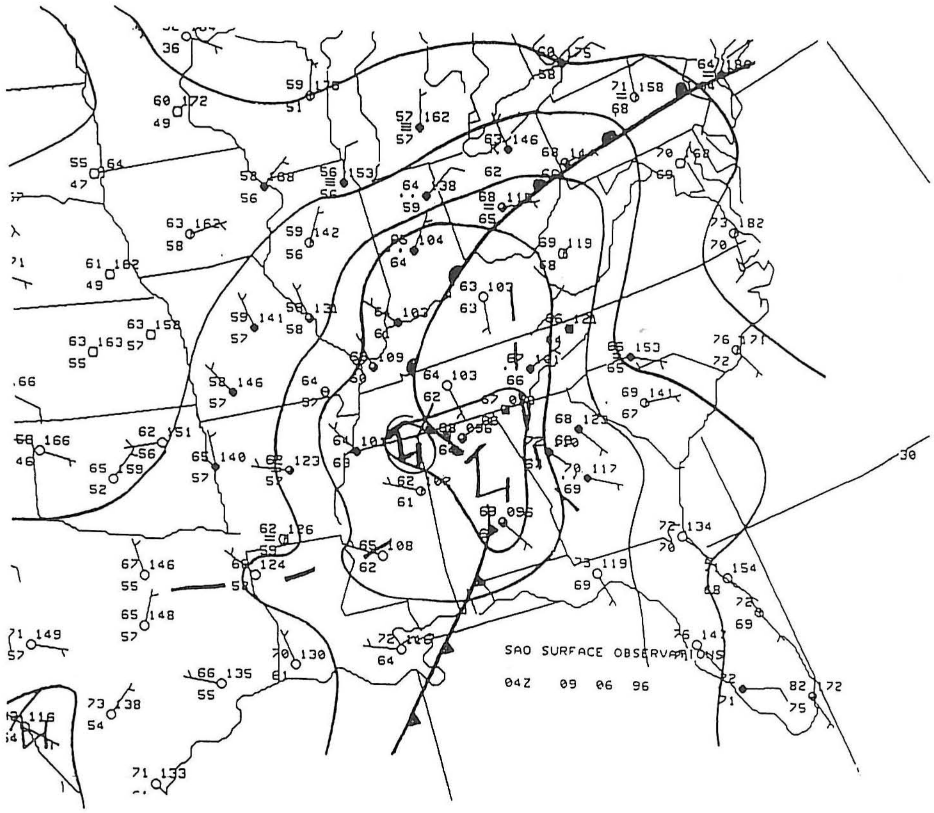

Fig. 1. Surface analysis 0400 UTC 9 June 1996.

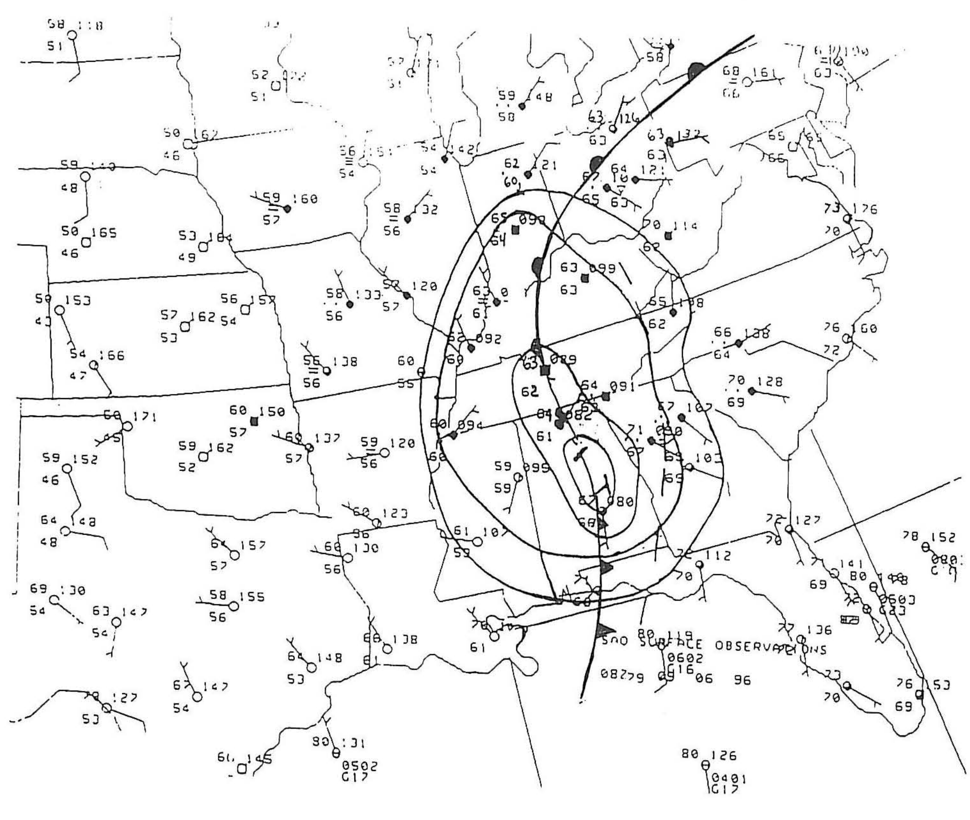

Fig. 2. Surface analysis 0800 UTC 9 June 1996.

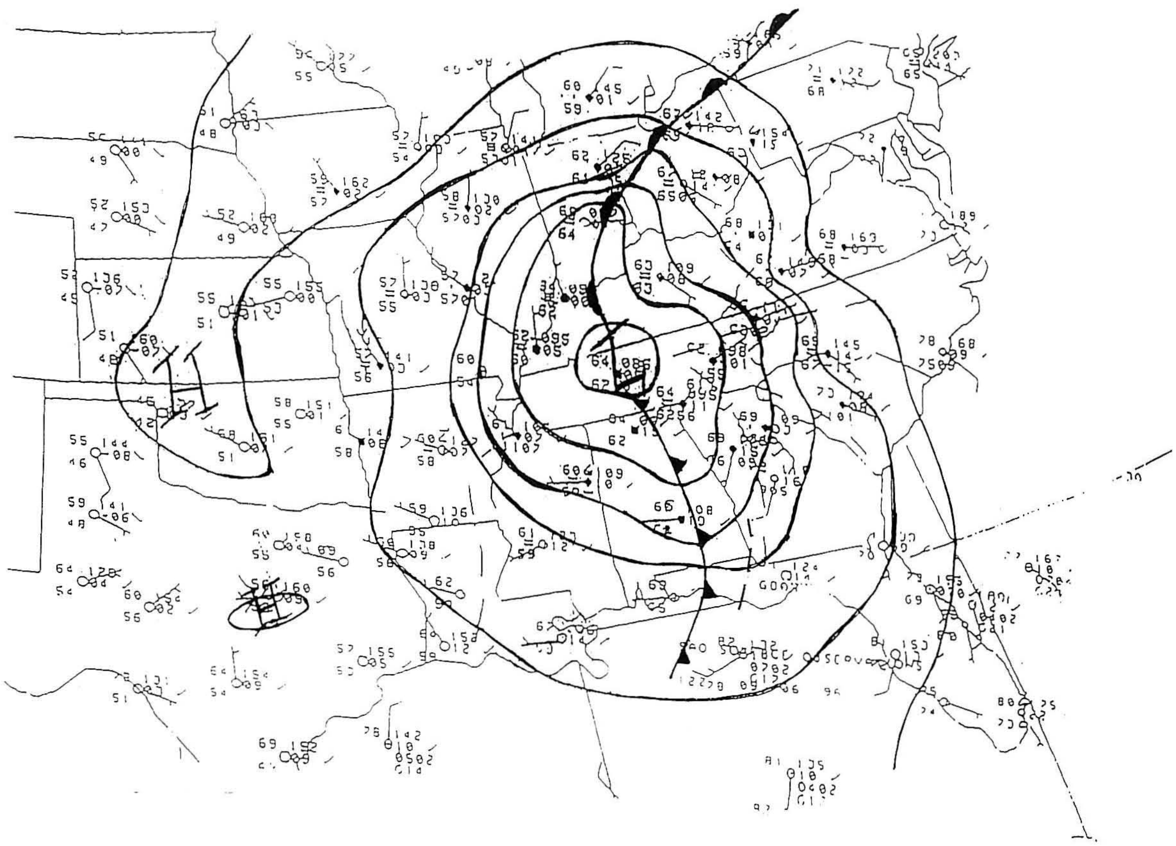

Fig. 3. Surface analysis 1200 UTC 9 June 1996.

By 0736 UTC, the composite reflectivity (Fig. 4) displayed a 65 to 70 dBZ reflectivity core. Additionally, close inspection showed a reflectivity void behind the apex of the developing bow echo, indicating the presence of a rear inflow notch/downdraft. However, the corresponding VIL and echo tops remained below severe thresholds based on VIL density criteria (Stewart 1992; Amburn and Wolf 1996). By the next volume scan (not shown), a fairly well-defined bow-echo feature was observed at the lowest elevation slices, while a high reflectivity core remained suspended aloft. The velocity data also began to show increasing wind speeds. While attached velocity Figs. 7 and 8 do not show substantial winds, this is misleading due to the fact that the storm is moving almost perpendicular to the radar beam. Estimating wind speeds using the angle between the storm motion vector and the radar beam yielded speeds greater than 100 knots. At this time, the first reports of damage were received at the National Weather Service Office (NWSO) Nashville (numerous trees and power lines were downed by strong winds).

Over the next 30 to 45 minutes, the storm continued to strengthen. The 0827 UTC composite reflectivity (Fig. 5) and 0833 UTC base reflectivity (Fig. 6) depicted a well-defined bow echo over Wilson County. Corresponding storm-relative velocity products (Figs. 7 and 8) and base velocity products (not shown) indicated significant shear near the apex of the bow, and the existence of rotating vortices at the ends of the bow (as indicated on Figs. 7 and 8). These vortices were referred to as "bookend" vortices by Weisman (1993).

The post-storm survey of the area through which the bow echo moved revealed 20 houses that sustained damage, four barns destroyed, several horses and cows killed, and numerous trees and power lines downed. Furthermore, the survey indicated that the majority of the damage was caused by straight-line winds near the apex of the bow. However, a couple of areas within the damage swath appeared to contain damage from tornadic-type rotation, and eyewitness reports verified this observation.

Post-storm analysis of the WSR-88D storm-relative velocity data indicated that the significant shear near the apex of the bow, and the area of rotation associated with the cyclonically-rotating bookend vortex at the edge of the bow (mentioned previously) appeared to correspond to the location of the tornadic damage revealed during the storm survey.

4. Summary

This case illustrates widespread straight-line wind damage associated with a bow echo, as well as weak, short-lived, non-supercellular tornadoes along the gust front, and near bookend vortices (in particular, the cyclonically rotating vortex). Throughout this event, echo tops remained below 35 thousand feet and VIL values hovered generally in the 30 to 35 range. The warnings issued were based almost solely on the bow-echo shape and the presence of suspended high-reflectivity cores.

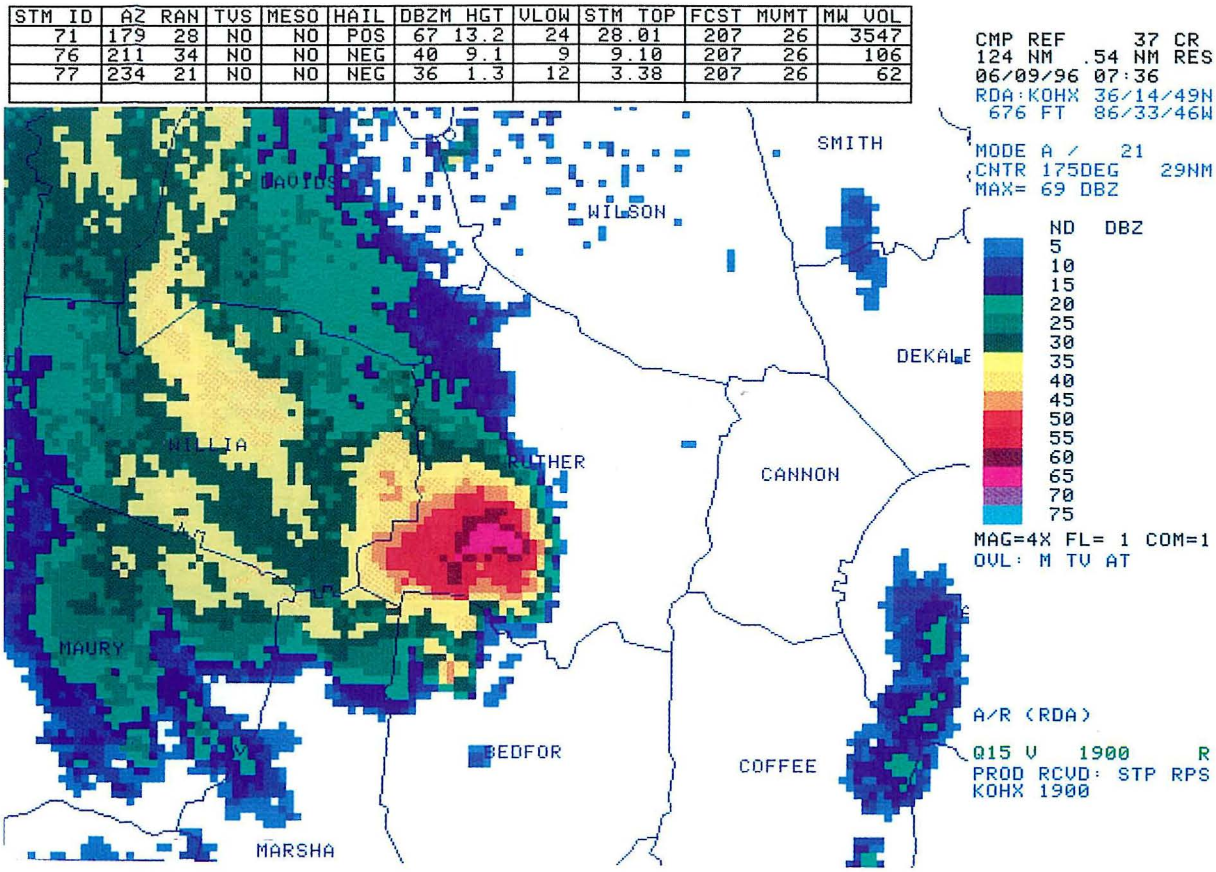

Fig. 4. WSR-88D composite reflectivity, 0736 UTC 9 June 1996.

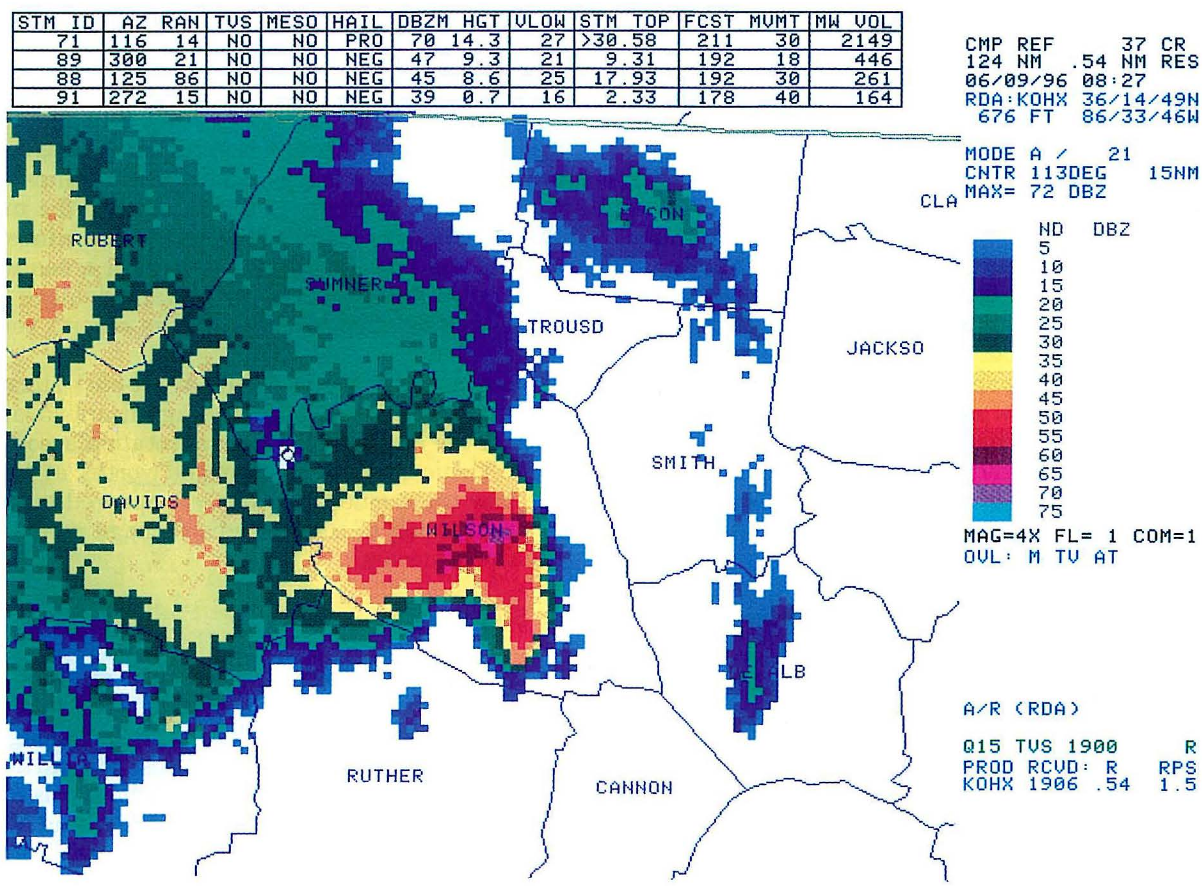

Fig. 5. WSR-88D composite reflectivity, 0827 UTC 9 June 1996.

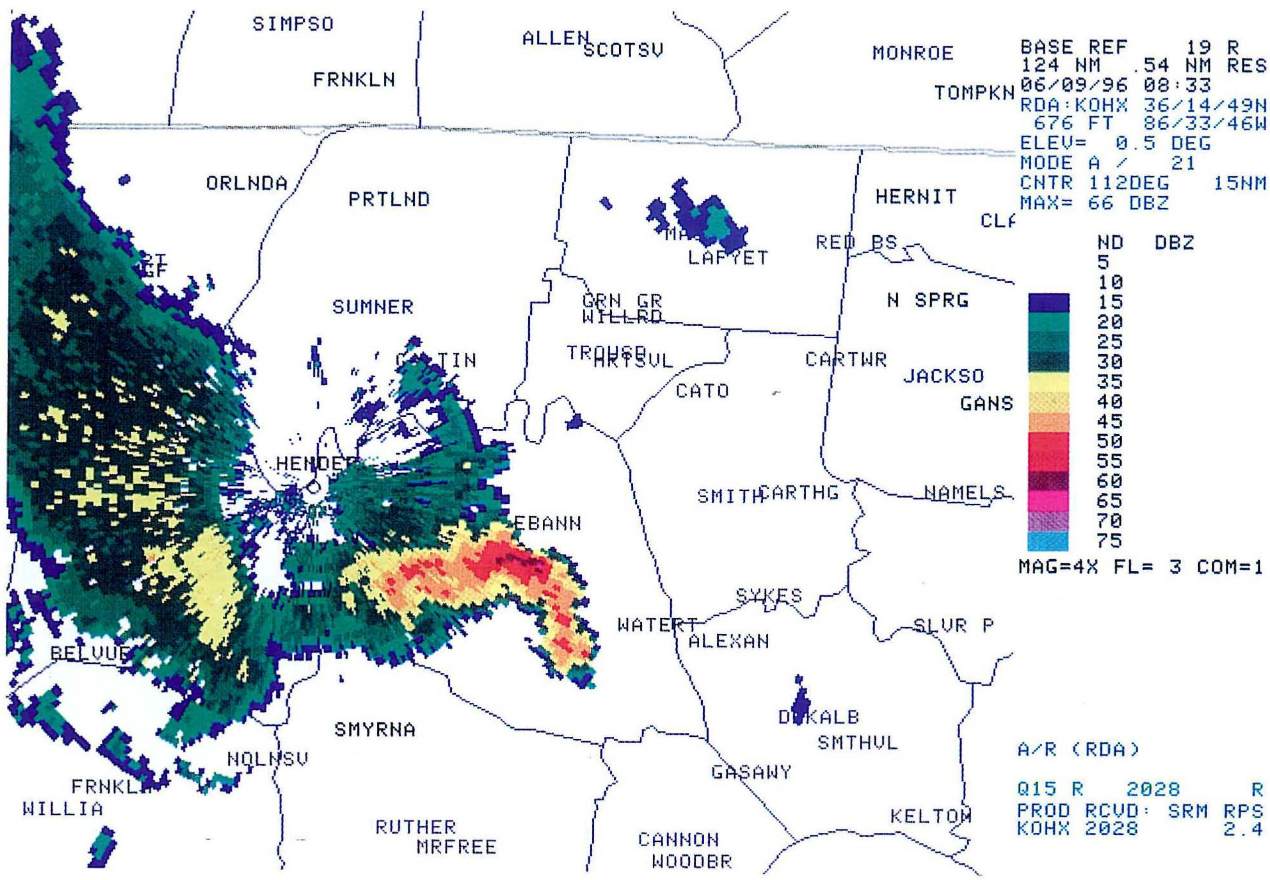

Fig. 6. WSR-88D base reflectivity at 0.5° elevation, 0833 UTC 9 June 1996.

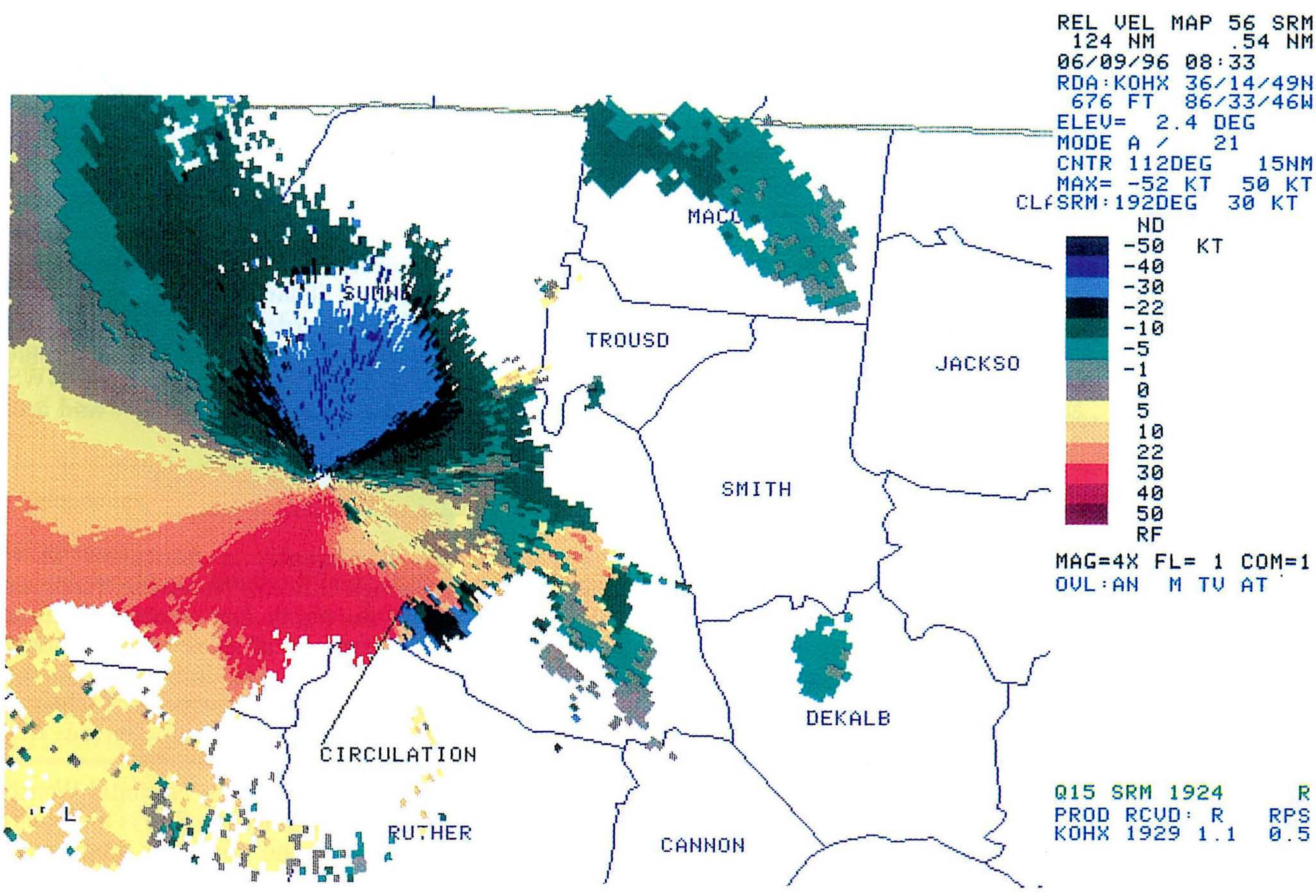

Fig. 7. WSR-88D storm-relative velocity at 3.4° elevation, 0827 UTC 9 June 1996.

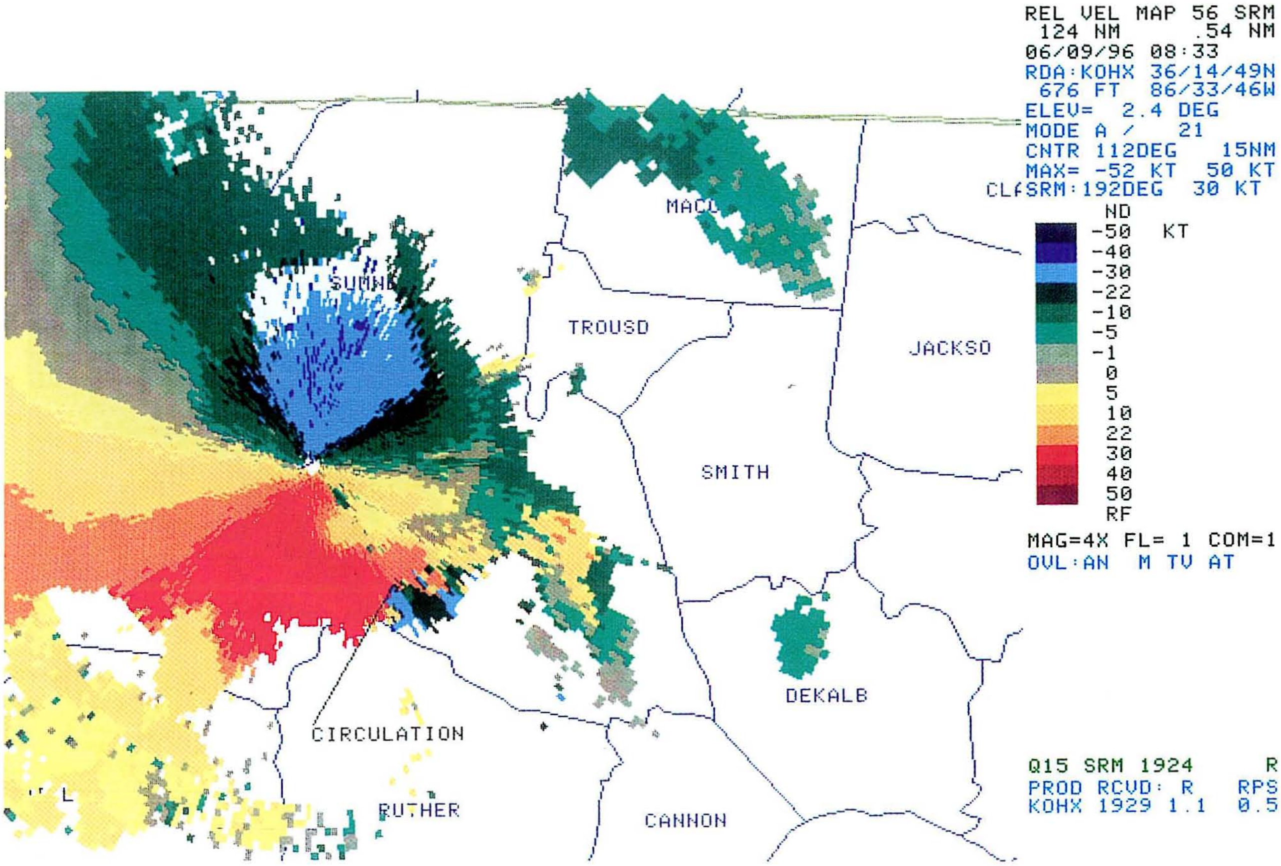

Fig. 8. WSR-88D storm-relative velocity at 2.4° elevation, 0833 UTC 9 June 1996.

The WSR-88D performed well, and even indicated the cyclonic and anticyclonic rotations at the ends of the bow echo. However, as expected, the WSR-88D did not indicate any TVS-like (Tornado Vortex Signature) circulations during this event (any tornadic circulations were likely very small spatially, and very shallow vertically). Obviously, any tornadoes that occur with non-supercellular storms will remain difficult to resolve directly using the WSR-88D velocity products. However, the shear areas near the apex of the bow as well as areas of rotation associated with the bookend vortices appeared to be the catalyst for the development of weak, short-lived tornadoes during this event. Past research of other cases supports these findings (Burgess and Smull 1990; Przybylinski and Schmocker 1993).

With more and more cases indicating that tornadoes or gustnadoes can, and often do, form *in the absence of mesocyclonic rotation* (Brady and Szoke 1988; Wakimoto and Wilson 1989), the question of what type of warning to issue — tornado or severe thunderstorm — can be raised. Further research will have to be conducted to determine what radar signatures could indicate tornadic activity, in addition to the straight-line wind damage normally expected during severe bow-echo events. In this case, areas of weak rotation at the ends of the bow, and strong shear near the apex of the bow appeared to correspond with the locations of observed tornadic damage. Perhaps these observations, along with the identification of environments favorable for the formation of non-supercellular tornadoes, can be used in future events to identify a storm's tornadic potential.

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References

Amburn, S. A. and P. Wolf, 1996: VIL density as a hail indicator. Preprints, *18th Conf. On Severe Local Storms*, San Francisco, Amer. Meteor. Soc., 581-585.

Brady, R. H. and E. Szoke, 1988: The landspout – a common type of northeast Colorado tornado. Preprints, *15th Conf. on Severe Local Storms*, Baltimore, Amer. Meteor. Soc., 312-315.

Burgess, D. W. and B. F. Smull, 1990: Doppler radar observations of a bow echo associated with a long-track severe windstorm. Preprints, *16th Conf. on Severe Local Storms*, Kananaskis Park, Canada, Amer. Meteor. Soc., 203-208.

Fujita, T. T., 1981: Tornadoes and downbursts in the context of generalized planetary scales. *J. Atmos. Sci.*, 38, 1511-1534.

Lee, B. D. and R. B. Wilhelmson, 1996: The numerical simulation of non-supercellular tornadogenesis. Preprints, *18th Conf. on Severe Local Storms*, San Francisco, Amer. Meteor. Soc., 408-412.

Stewart, S. R., 1992: An empirical forecasting technique for predicting pulse-type thunderstorm gusts using radar derived vertically integrated liquid (VIL) and the penetrative downdraft mechanism. A Non-Thesis., University of Oklahoma School of Meteorology, 83 pp.

Przybylinski, R. W. and G. K. Schmocker, 1993: The evolution of a widespread convective windstorm event over central and eastern Missouri. Preprints, *13th Conf. on Weather Analysis and Forecasting*, Vienna, Virginia, Amer. Meteor. Soc., 461-465.

Wakimoto, R. M. and J. W. Wilson, 1989: Non-supercell tornadoes. *Mon. Wea. Rev.,* 110, 707-718.

Weisman, M. L., 1993: The genesis of severe, long-lived bow echoes. *J. Atmos. Sci.*, 50, 645-670.