P12.4 LOW-LEVEL CIRCULATIONS AS OBSERVED BY CASA AND NEXRAD ON 10 FEBRUARY AND 13 MAY 2009

J. Brotzge[1] and V. Mahale[2]

[1]*Center for Analysis and Prediction of Storms, University of Oklahoma*
[2]*School of Meteorology, University of Oklahoma*

1. INTRODUCTION

One of the foremost challenges for operational forecasters is determining whether or not to issue a tornado warning. Currently, well over 40% of all tornadoes may not be warned (Brotzge and Erickson 2009a), up to 10% of reported tornadoes are warned only after initial tornado touchdown (Brotzge and Erickson 2009b), and about 75% of tornado warnings are false alarms (National Weather Service 2007). Nevertheless, forecasters must often make quick decisions on whether or not to warn with only limited information. Field reports from storm spotters are relatively sparse in rural areas and at night, and weather radar coverage is limited with distance from radar due to the earth curvature and because of beam blockage from mountainous terrain. Data show that the ratio of tornadoes warned decreases with distance from radar, meaning that this lack of information impedes forecasters from making better warning decisions (Brotzge and Erickson 2009b).

The problem of limited radar coverage at low levels is being addressed. The National Science Foundation established the Engineering Research Center for the Collaborative Adaptive Sensing of the Atmosphere (CASA; McLaughlin et al. 2009) in 2003 with the goal to design and deploy a low-cost, low-power radar system to improve surveillance of the lower atmosphere. To test and demonstrate its new technologies, CASA deployed a test bed of four X-band radars in southwestern Oklahoma in fall 2006. Since that time, all four radars have been operated routinely each spring and fall during the severe weather seasons.

This study compares the single radar reflectivity and velocity data from NEXRAD and CASA collected from two severe storms on 10 February and 13 May 2009. The 10 February storm produced four areas of strong rotation within the test bed area, but with no confirmed tornado touchdowns. The 13 May storm produced an EF2 tornado. This study examines how well each radar system scanned each area of circulation and how National Weather Service (NWS) warnings could be improved with additional low-level radar coverage as provided by a CASA-like system.

Corresponding author address: Dr. Jerry Brotzge, Center for Analysis & Prediction of Storms, Univ. of Oklahoma, Norman, OK 73072 jbrotzge@ou.edu

2. THE CASA TEST BED

The CASA radar network (Junyent et al. 2009) is comprised of four dual-polarization X-band radars, located approximately 100 km to the southwest of Oklahoma City. Each radar has a beam width of 1.8°, oversamples every 1°, and has a range of about 40 km. The CASA network is designed with overlapping radar coverage to provide dual-Doppler capability and to provide multiple radar viewing angles in part to correct for radar attenuation (Chandrasekar and Lim 2008). Each CASA radar samples collaboratively and adaptively. Data from all four radars flow to a central processing site, where the data are merged to form a single integrated two-dimensional grid. Then the data are mined to identify areas of interesting features as designated by the users of the system, e.g., areas of significant shear or high reflectivity. New scanning strategies then are developed around the objects identified from the data mining. New scan strategies are generated and transmitted to the radars automatically every minute. Each radar scan strategy allows for adaptive (sector) scanning, while operating in a coordinated fashion with neighboring radars. CASA data are provided each minute, compared to five-minute updates from NEXRAD.

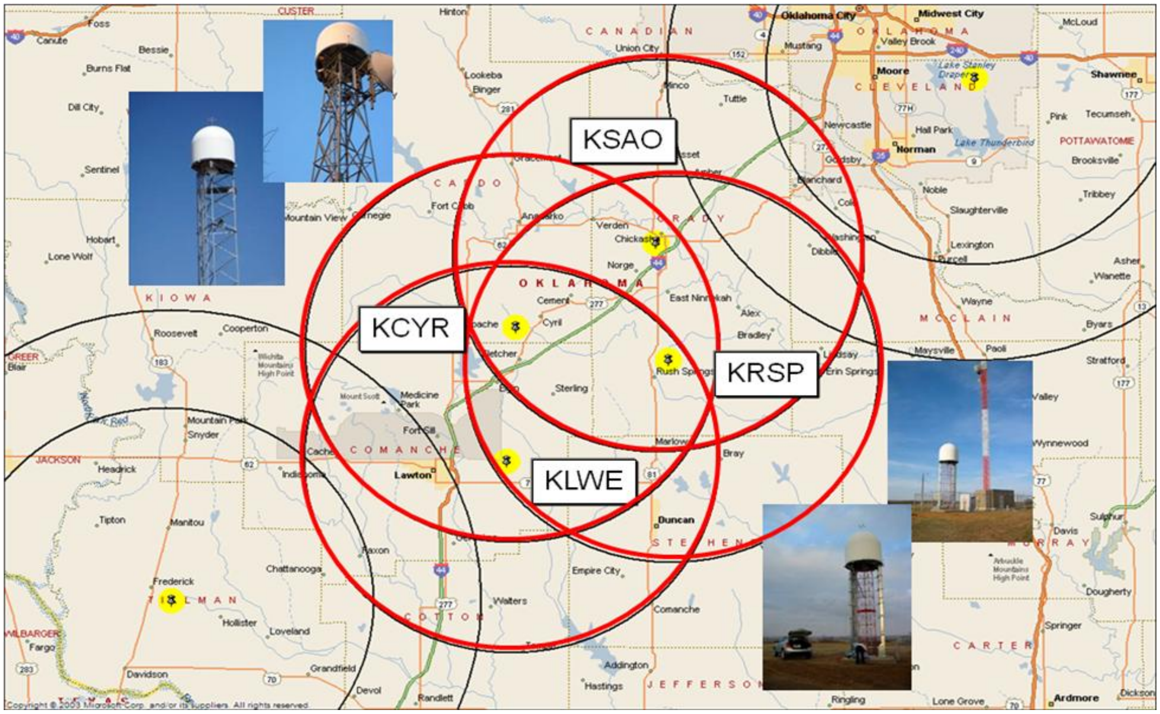

Fig. 1: The four CASA radar sites are located near the cities of Cyril (KCYR), Lawton (KLWE), Rush Springs (KRSP), and Chickasha (KSAO). Range rings of 40 km are shown in red around each CASA radar. The nearest NEXRAD radars are KTLX and KFDR; range rings of 40 km and 60 km are shown.

3. 10 FEBRUARY SEVERE STORM

A line of strong storms formed over central Oklahoma on the afternoon of 10 February 2009 along a north-south oriented stationary front. An upper-level trough approached from the west with increasing shear with height. Warm, moist southeasterly flow dominated east of the boundary with dewpoints approaching 60° F; much drier southwesterly flow prevailed west of the trough.

The first storm began to initiate within the CASA test bed by 1900 UTC. Several strong storms had developed rapidly by 1940 UTC, and by 2040 UTC one of these storms had moved north into the Oklahoma City metropolitan area and produced a damaging tornado. New storms continued to initiate to the southwest, training over the same areas of the CASA test bed. Between 2000 UTC and 2200 UTC, four low-level circulations had moved north across the CASA domain. All four circulations were observed by both NEXRAD and CASA. However, a strong but brief intensification of the third circulation was observed only by the one-minute CASA scans.

Detailed images of this third low-level circulation are shown from both CASA (Fig. 2) and NEXRAD (Fig. 3). CASA scanned the vortex with a one degree elevation angle at a minimum height of approximately 600 m AGL at a range of 10 km, while NEXRAD scanned the circulation area with a half degree elevation angle at a minimum height of about 2.0 km AGL at a range of 105 km. Without subtraction of the storm motion, virtually no azimuthal shear was visible from NEXRAD. With a storm motion of 60° at 10 m s^{-1} removed, a maximum azimuthal wind shear of about 0.009 s^{-1} was estimated from NEXRAD. The maximum shear as estimated from CASA was about double that measured by NEXRAD at 0.020 s^{-1}. Because of the nearly perpendicular orientation of the CASA radar beam to the storm motion, subtraction of the storm motion had virtually no effect on the CASA shear estimates. In contrast, the nearly parallel orientation of the NEXRAD beam to the storm motion made it more difficult to detect the circulation.

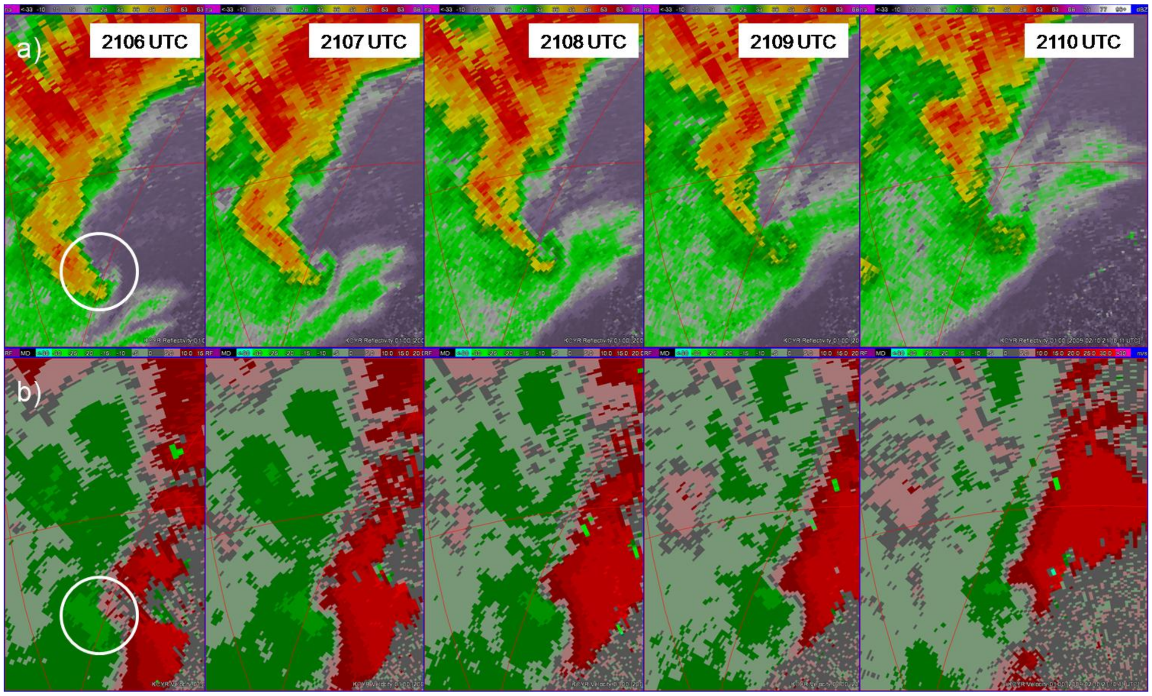

Fig. 2: CASA (a) reflectivity and (b) velocity data collected between 2106 UTC and 2110 UTC on 10 February 2009. Data collected at 1 degrees elevation from the KCYR radar near Cyril. The area of circulation is highlighted by the white circle.

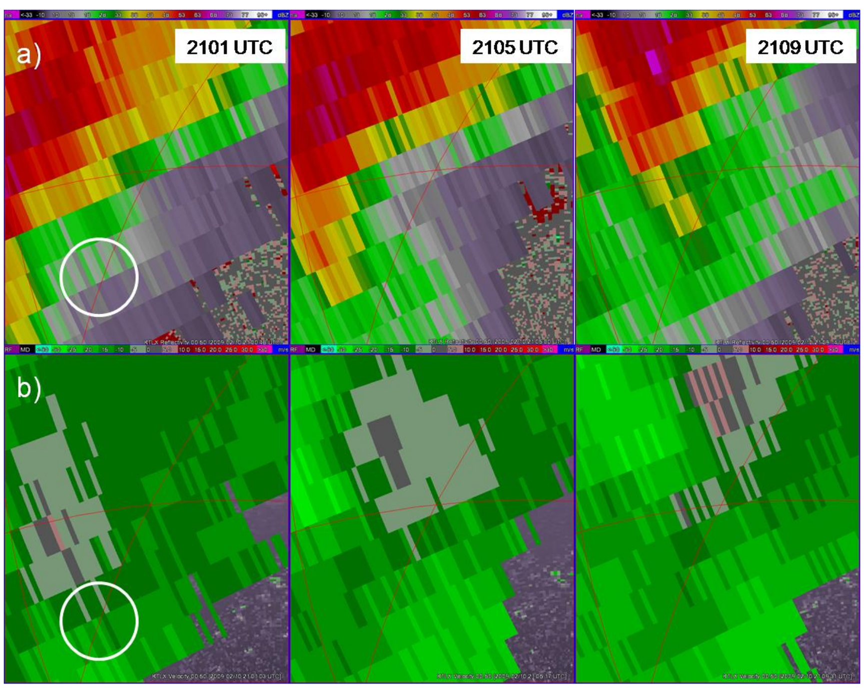

Fig. 3: NEXRAD (a) reflectivity and (b) velocity data collected between 2101 UTC and 2109 UTC on 10 February 2009. Data collected at 0.5 degrees elevation from the KTLX radar located east of Norman, Oklahoma.

What impact, if any, would the additional information from CASA had on the NWS tornado warning process? The circulation as shown in Figs. 3 and 4 had no NWS tornado warning associated with it, though this was due primarily to the presence of a significant cold pool at the surface remaining from the passage of several previous storms. Nevertheless, according to NWS personnel a tornado warning likely would have been issued on this storm if they had access to the real-time information from CASA during this event. A severe thunderstorm warning was in effect for the entire county throughout the lifetime of the storm.

4. 13 MAY TORNADO

A line of strong to severe storms formed during the late afternoon of 13 May along a sharp cold front that advanced southward towards central Oklahoma. Vertical wind shear was moderate, and the thermodynamic profile represented a classical 'loaded gun' sounding with warm moist, southeasterly flow near the surface and much drier, cooler, westerly air aloft. Surface dewpoints approached 72° F. The 0000 UTC sounding from OUN measured a surface-based Convective Available Potential Energy (CAPE) of over 4500 J kg^{-1} and 0-1 km helicity of 120 m^2 s^{-2}.

The southernmost storm of the convective line developed rapidly just to the north of the CASA test bed by 0200 UTC and moved south into the test bed. By 0215 UTC, low-level rotation was evident from both NEXRAD and CASA, and the NWS issued a tornado warning at 0224 UTC effective until 2045 UTC. Both NEXRAD and CASA observed the area of rotation throughout the warning period (Fig. 4, Fig. 5).

A comparison of data collected by CASA and NEXRAD identify several significant advantages by the CASA system over the WSR-88Ds. First, a dense network of short-range radars inherently provides an advantage over longer range radars in that each radar is closer to the phenomenon being observed. This allows for greater spatial resolution (assuming all other radar parameters are equal). In this example, the CASA radar (KSAO) was only 28 km from the tornado, while KTLX was 89 km away. Second, a greater volume of the lower atmosphere can be scanned by a dense network of radars than by long-range radars. A dense network of radars overcomes the "earth curvature" problem. For this case, the center of the beam of the lowest elevation angle from KSAO (1° elevation) scanned the tornado at a height of 900 m AGL; KTLX scanned it at a height of 1.6 km AGL using its lowest elevation angle of 0.5°. Third, the adaptive scanning capabilities of CASA allowed for much faster updates; new data are provided to the forecaster each minute from CASA while full volume scans from NEXRAD require 4 – 6 minutes.

The advantages of the CASA network provide the forecaster with much greater detail regarding storm structure and development. For example, a review of the NEXRAD data from 13 May shows a significant low-level circulation and inflow notch (Fig. 5). However, the one-minute images from CASA further reveal a strengthening area of rotation and subsequent occlusion with what appears to be a rear flank downdraft spreading to the east and north around the tornado vortex (Fig. 4).

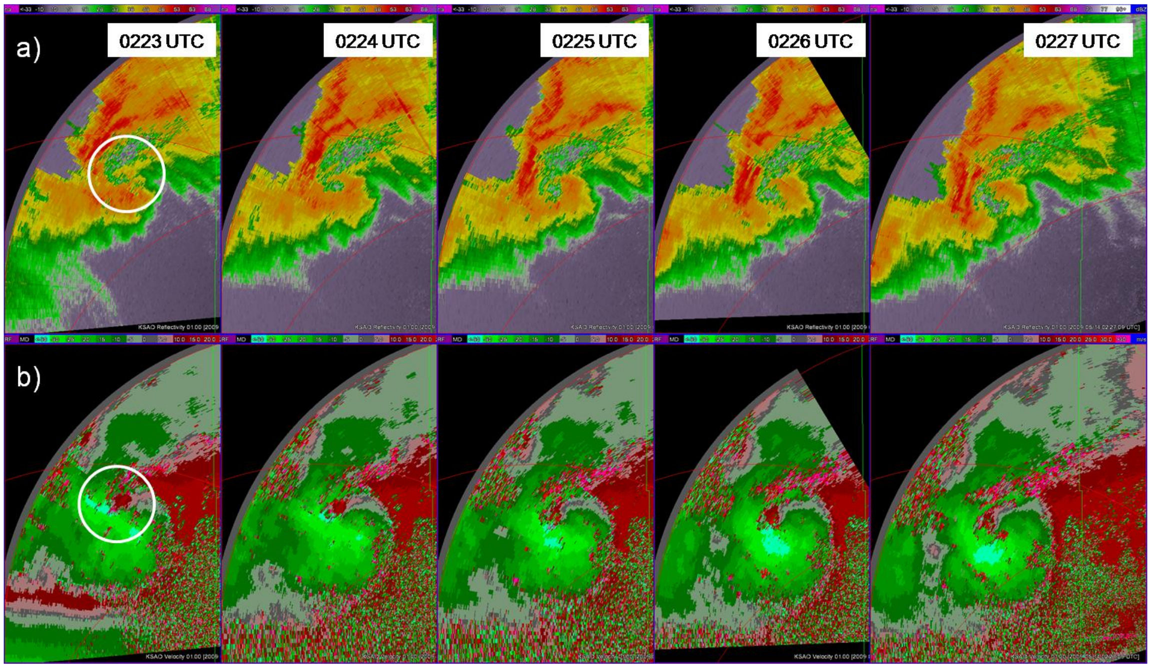

Fig. 4: CASA (a) reflectivity and (b) velocity data collected between 0223 UTC and 0227 UTC on 14 May 2009. Data collected at 1 degrees elevation from the KSAO radar in Chickasha. The area of circulation is highlighted by the white circle.

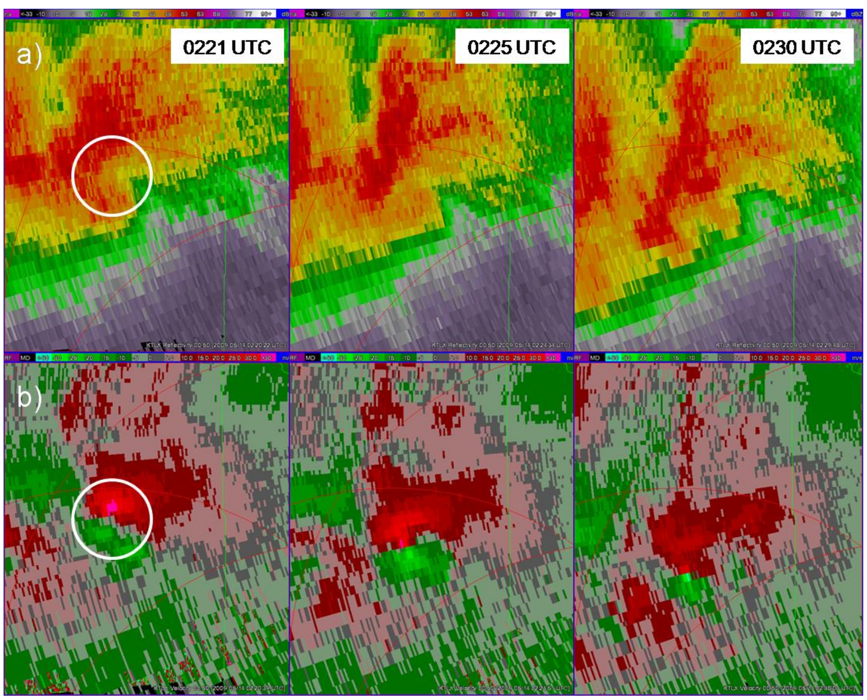

Fig. 5: NEXRAD (a) reflectivity and (b) velocity data collected between 0221 UTC and 0230 UTC on 14 May 2009. Data collected at 0.5 degrees elevation from the KTLX radar located east of Norman, Oklahoma.

The circulation intensity as estimated by NEXRAD and CASA were comparable at similar heights of measurement. For the times shown in Figs. 4 and 5, the maximum shear measured from NEXRAD was about 0.049 s^{-1} at 1.6 km AGL compared with a maximum shear velocity of 0.050 s^{-1} as estimated from KSAO at 1.4 km AGL. However, the tornado is believed to be most intense near the surface (Lewellen and Lewellen 2007). Furthermore, while a mesocyclone may exist at mid-levels, lower level measurements are needed to confirm that a funnel has made contact with the ground. CASA's ability to scan lower in the atmosphere provides the forecaster with this additional information. In this example, the lower level data from CASA shows a stronger vortex nearer the surface; the maximum shear velocity as estimated at 900 m AGL (using the 1° elevation angle) was 0.062 s^{-1}, more intense than that measured 0.5 km higher.

Polarimetric data has been shown as a reliable aid in the detection of damaging tornadoes (Ryzhkov et al. 2005). For example, a minimum in the ρ_{hv} field is believed to indicate airborne debris. Sample polarimetric data from KSAO collected during the 13 May event shows a relative minima in the ρ_{hv} during the time at which the greatest damage was believed to have occurred (Fig. 6a). Coincident velocity data are shown in Fig. 6b.

So how could operational forecasters improve their warning process for this scenario? A tornado warning was issued at 0224 UTC, at or just before tornado touchdown. Off-duty forecasters, participating as part of the Experimental Warning Program 2009 Spring Experiment (see Stumpf et al. 2008), issued a tornado warning one to two minutes prior to the NWS based on inclusion of CASA data and the use of derived wind products. The finer resolution data allows for more detailed warnings and provides forecasters with a much more comprehensive understanding of the evolving situation.

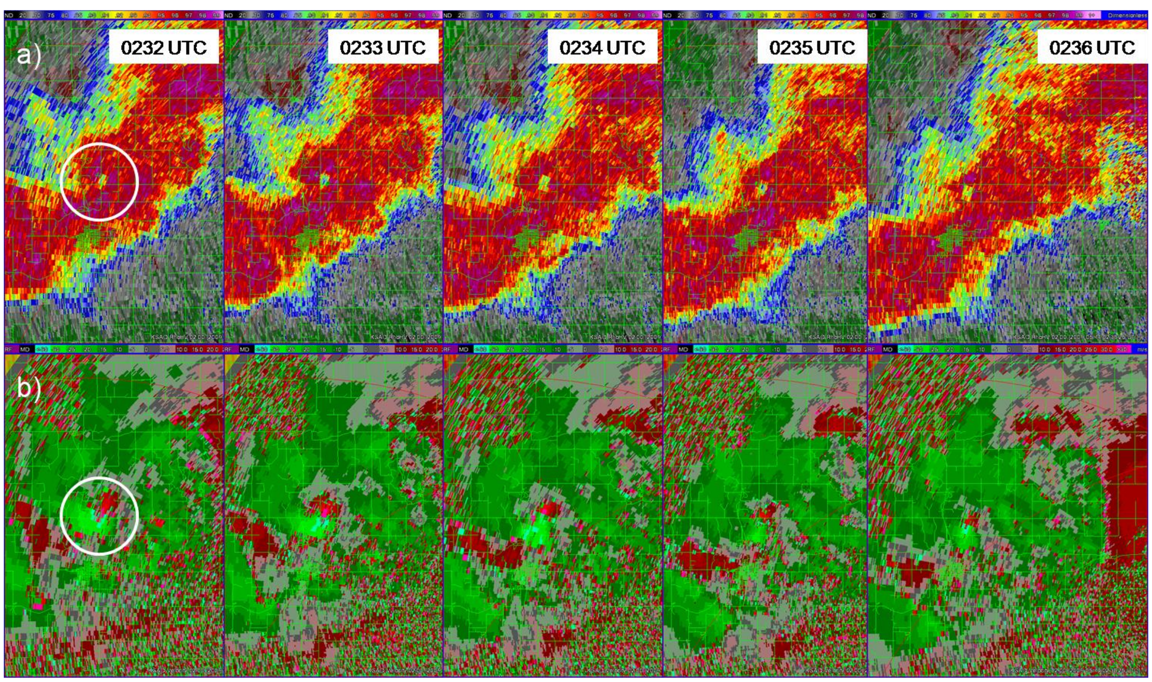

Fig. 6: CASA (a) ρ_{hv} and (b) velocity data collected between 0232 UTC and 0236 UTC on 14 May 2009. Data collected at 2 degrees elevation from the KSAO radar in Chickasha. The area of debris and associated circulation is highlighted by the white circle.

5. DISCUSSION AND SUMMARY

The geometry of a dense network of short-range weather radars provides several key advantages over conventional radar networks for observing and tracking severe weather. A network of dense radars overcomes the earth-curvature problem with phenomena observed nearer to radar, and such a system provides more routine and thorough coverage within the lowest 3 km AGL. Adaptive, sector scanning also permits faster volume scanning of those storms and features of greatest interest. Furthermore, while this paper has focused on the advantages of single radar data, the merging of data from multiple radars or radar systems with overlapping coverage is critical for attenuation correction, dual-Doppler analysis, and data assimilation and prediction. The assimilation of CASA radar data into numerical forecast models has shown to significantly improve some mesoscale model forecasts (e.g., Schenkman et al. 2008) and could be critical to the successful implementation of 'warn on forecast'. Finally, the adoption of dual-polarimetric technology will improve detection and warning of severe weather phenomena by providing additional insight into storm cloud physics, hydrometeor type, and the identification of debris.

Two case studies were examined. A severe thunderstorm on 10 February 2009 produced a brief and significant low-level circulation that failed to produce a tornado. This brief intensification was documented by CASA but largely was missed by NEXRAD. An EF2 tornado was observed on 13 May 2009. Data from both NEXRAD and CASA captured this event. However, the much finer resolution data from CASA provided detailed information on the evolution and occlusion of the tornado not evident from NEXRAD.

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