P2.15 **A Case Study Evaluating Distributed Collaborative Adaptive Sensing: Analysis of the 8 May 2007 Minisupercell Event**

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1. INTRODUCTION

The Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) is a ten-year Engineering Research Center established by the National Science Foundation for the development of small, inexpensive, low-power radars designed to improve scanning of the lowest levels (< 3km AGL) of the atmosphere. Instead of sensing autonomously, CASA radars are designed to operate as a network, collectively adapting to the changing needs of end-users and the environment; this network approach to scanning is known as *Distributed Collaborative Adaptive Sensing* (DCAS). DCAS improves data quality and maximizes the utility of each scanning cycle. A testbed of four prototype CASA radars were deployed in southwestern Oklahoma in 2006 and operated continuously while in DCAS mode during March through June of 2007.

During the evening of 8 May 2007 a mesoscale convective system associated with an atypical mesoscale convective vortex (MCV; Davis and Trier 2007), moving north from TX into OK, spawned one supercell and three minisupercells (each approximately 5 km in diameter) within the CASA testbed. Four circulations including three misocyclones (each velocity 'couplet' approximately 1 km in diameter) were tracked by the CASA radars between 00 UTC and 04 UTC; the fourth circulation producing a brief EF1 tornado.

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This paper is an analysis of the 8 May 2007 event, with a special focus on evaluating the benefits and weaknesses of the DCAS scanning strategy. Data collected from nearby WSR-88Ds and CASA radars are compared. Initial results indicate that the high temporal (60-sec) and spatial (100-m) resolution provided by DCAS yields much-improved temporal and spatial feature continuity and tracking. Moreover, the DCAS system is able to resolve a whole class of circulations, the misocyclone (Kessinger et al. 1988), far better than the WSR-88D. In fact, many of these are probably missed completely by the WSR-88D.

2. CASA NETWORK

The CASA radar network is an engineered system comprised of several modular components including radar hardware and signal processing; communications; a suite of feature detection algorithms (known as the Meteorological Command and Control (MC&C) system); and optimization software. The current generation CASA radars are low-power, dual-polarization, X-band radars with a beamwidth of 1.8 degrees and azimuthal oversampling of one degree (with an effective beamwidth of about 2 degrees (Brown et al. 2002)) and a range gate of 100 m. This is in comparison with the pulse volume size from NEXRAD of approximately one degree by 1 kilometer (250 m) for reflectivity (velocity). The CASA radars have a peak (mean) power of 25 kW (25 W). Signal processing is done at the radar site. Clutter mitigation and attenuation correction are applied in real-time. Attenuation is corrected in one of two ways. Single radar data are corrected using the dual-polarization variables (Gorgucci and Chandrasekar 2005), and data within multi-

Doppler regions can be corrected by merging data from multiple radars (Lim et al. 2007). In areas of very high reflectivity, the return signal is completely attenuated. Moment data generated at the radar tower are transmitted via wireless microwave links to a central location for data merging and archival.

Data from all radars are “mined” by the MC&C (Brotzge et al. 2005), a package of data-mining algorithms that search the data for features of interest (e.g., high reflectivity, areas of strong wind shear). Next, a new set of scanning tasks are produced by the optimization software. The optimization software considers sensing and weather information as well as the needs of competing end-users to develop each new set of radar scanning tasks (Philips et al. 2007). These new tasks are then sent to the radars to perform during the next scanning cycle. This work flow cycle is completed once each minute.

The first CASA testbed (Figure 1) is located in southwestern Oklahoma and is comprised of four low-power, X-band (3-cm) radars. These four radars are located approximately 25 km apart in or near the towns of Cyril (KCYR), Lawton (KLWE), and Rush Springs (KRSP), and on the campus of the University of Science and Arts of Oklahoma in Chickasha (KSAO). The radars were located midway between two existing WSR-88D radars in part to “fill in gaps” in scanning below 1 km AGL (Brewster et al. 2005) and with overlapping coverage to enable multi-Doppler analysis.

3. CASE STUDY

During the day and evening of 8 May 2007 a surface low developed in southwest Oklahoma at the intersection of a stalled east-west frontal boundary and a surging cold front to the west (Figure 2a). As the cold front moved rapidly east, an MCV formed south of the Red River in northwest Texas. As the stationary front lifted north into central Oklahoma, warm humid air saturated the lowest levels (Figure 2b), while the MCV acted to enhance low-level wind shear. Together, atmospheric conditions were favorable for severe weather with isolated tornadoes possible. The National Weather Service issued a Tornado Watch at 2230 UTC covering portions of northwest and north central Texas and southwestern Oklahoma (Figure 3).

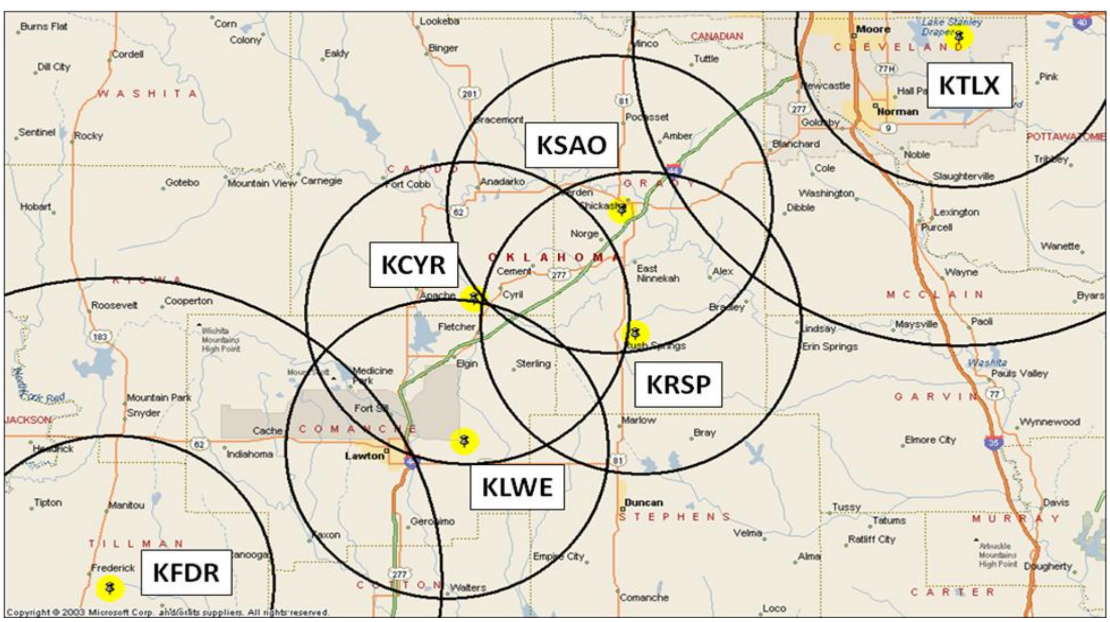

Figure 1: The first CASA testbed is located in southwestern Oklahoma. The four radars are located in or near the towns of Chickasha (KSAO), Cyril (KCYR), Lawton (KLWE), and Rush Springs (KRSP). The nearest WSR-88D radars are near the towns of Frederick (KFDR) and Twin Lakes (KTLX). Range rings of 30 km and 60 km are marked.

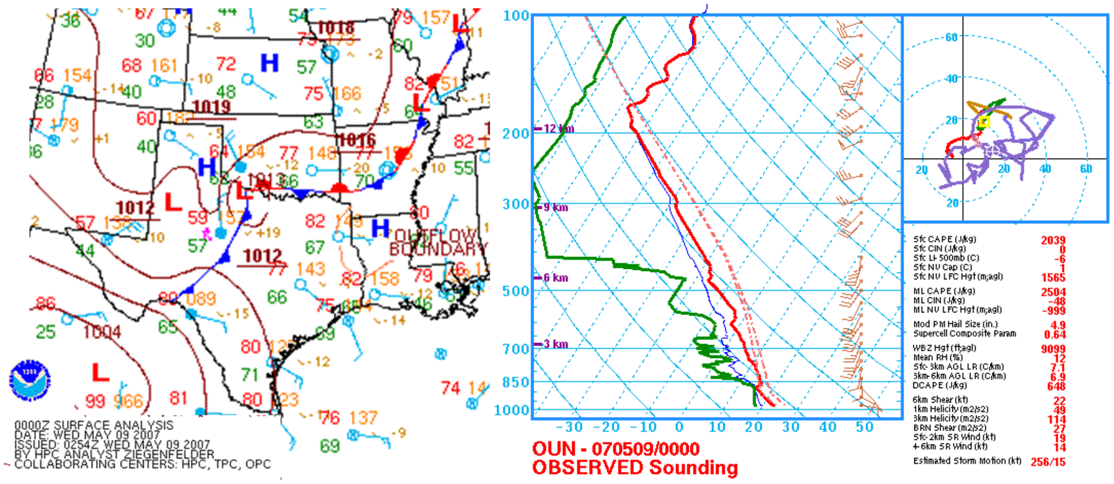

Figure 2: a) Analyzed surface map for 0000 UTC 9 May 2007. b) Skew-T diagram and hodogram of the upper-air sounding collected at 0000 UTC 9 May from Norman, Oklahoma.

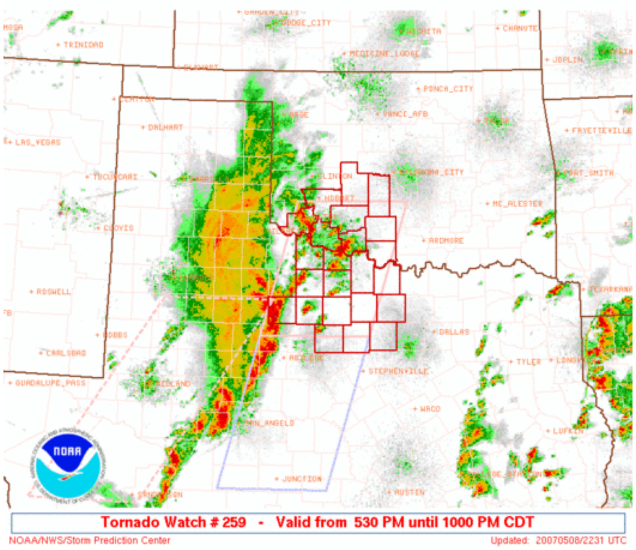

Figure 3: Radar composite at 2231 UTC. A thunderstorm watch was issued at 2040 UTC (as outlined by the blue rectangle) and was superseded by a tornado watch (counties in red) issued at 2230 UTC.

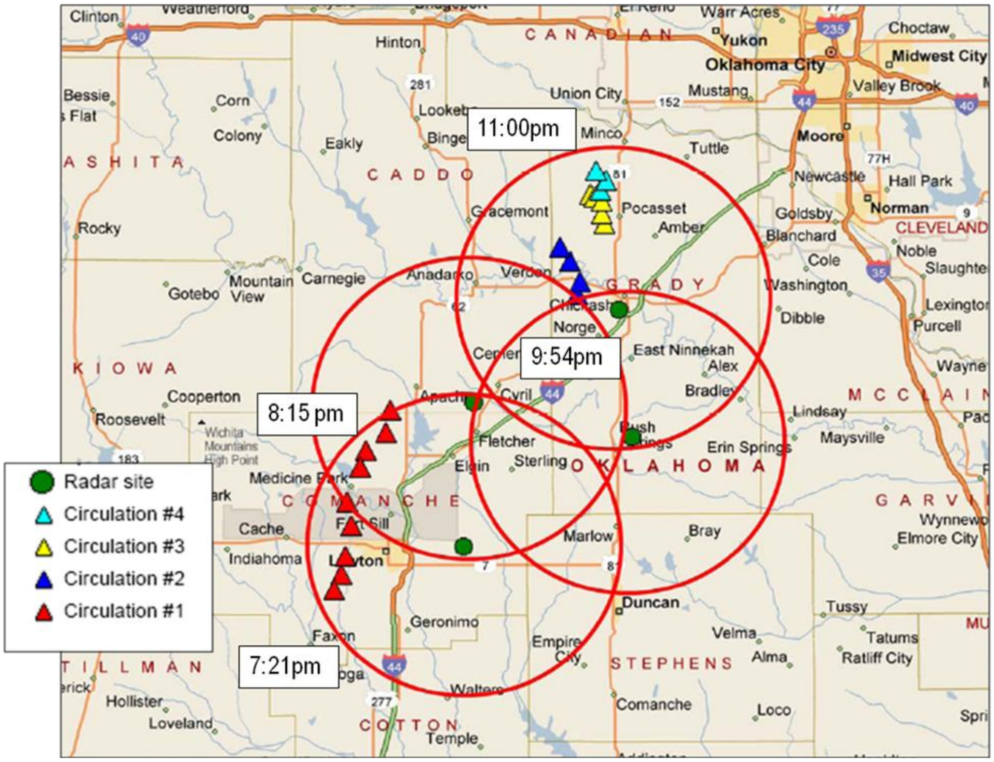

Figure 4: Map shows the four CASA radars (indicated with green circles) and the circulation areas observed during the 8 May 2007 event (indicated with triangles). For this event, CASA radars each had a range of 30-km (indicated with red circles).

Figure 5: a) Photo taken with a cell phone just east of Lawton, Oklahoma, associated with circulation #1. b) Damage observed near the town of Minco caused by the EF1 tornado spawned from circulation #4.

Four significant, low-level circulations, possibly misocyclones, were observed between 0000 UTC and 0400 UTC within the CASA network (Figure 4). One brief EF0 tornado was reported in association with circulation #1 (Figure 5a) by a television storm chaser, but this report could not be confirmed by a follow-up damage survey team. One EF1 tornado was confirmed near Minco, Oklahoma, associated with circulation #4 (Figure 5b).

4. COMPARISON OF CASA AND NEXRAD

Severe storms entered the CASA network from the south at approximately 0000 UTC and exited the network to the north at nearly 0400 UTC (9 May). Two distinct phases of this storm event will be discussed. First, a supercell was observed by the CASA radar near Lawton (KLWE) moving north between 0000 UTC and 0100 UTC. A low-level circulation was detected with this supercell, and one EF0 tornado was reported. Second, a series of three misocyclones were observed by the CASA radar at Chickasha (KSAO) between 0300 and 0400 UTC moving north away from the CASA testbed. Unfortunately, both storm episodes were observed primarily within the single-radar coverage of CASA and many of the advantages of the CASA testbed (e.g., dual-Doppler analysis, multi-Doppler attenuation correction) could not be realized. Nevertheless, the high temporal and spatial resolution and low-level coverage enabled by the CASA radars provides additional insight into the development and progression of this particular event.

4.1 Supercell near Lawton, 0000 – 0100 UTC

As the developing supercell enters the CASA network at about 0000 UTC, the CASA network Meteorological Command and Control (MC&C) system recognizes the storm as a “feature of interest” due to its high reflectivity and begins scanning the storm in DCAS mode. Of all four CASA radars, this storm can only be observed from the KLWE radar, so KLWE is instructed to scan the storm in an approximate 60 degree azimuth sector encompassing the storm at 1, 2, 3, 5, 7, 9, 11, and 14 degree elevations.

By 0015 UTC, a vortex is observed in the CASA velocity data coincident with an appendage now observed in the CASA reflectivity. A ‘hook’ feature forms between 0015 and 0020 UTC as evident in the KLWE data, and by 0026 UTC a pronounced hook is clearly observed in the CASA reflectivity data. This feature persists in the KLWE reflectivity until ~ 0040 UTC (Figure 6a). By 0045 UTC the hook and appendage has dissipated though a weakened area of shear persists.

Data collected from the WSR-88D radar near Fredrick (KFDR) between 0028 UTC and 0040 UTC are shown in Figure 6b. Data from KFDR are available from the lowest elevation angle only once every five to six minutes compared with once per minute from CASA. In addition, the spatial resolution provided by the KFDR reflectivity is about 1km compared with 100 m from KLWE. Finally, KFDR is about 50 km from the circulation area compared with ~ 22 km from KLWE. Given these distances, the center of the beam of the one degree elevation angle from KLWE is observing the storm at approximately 400 m AGL compared to the center of the beam at one half degree elevation angle from KFDR scanning at a minimum height of approximately 580 m AGL.

The higher temporal and spatial resolution provided by CASA better captures the cyclical behavior in the growth and decay of the storm circulation. When the maximum shear velocity couplet from each radar is compared at each time step, the true signal is found to be undersampled by KFDR (Figure 7).

One key advantage of the CASA configuration is its ability to scan within the lowest 1 km AGL. An examination of data from KCYR between 0130 UTC and 0200 UTC shows the supercell evolve into an outflow dominated storm, whereby the outflow undercuts the mid-level circulation. No low-level vorticity couplet could be detected from KCYR after 0140 UTC (Figure 7b). At this time the lowest elevation scan from KCYR was scanning at ~ 550 m AGL while KFDR was scanning at approximately 1100 m AGL. This case is one example where additional radar coverage below 1 km could have impacted the duration of the tornado warning, in this case, shortening the tornado warning period.

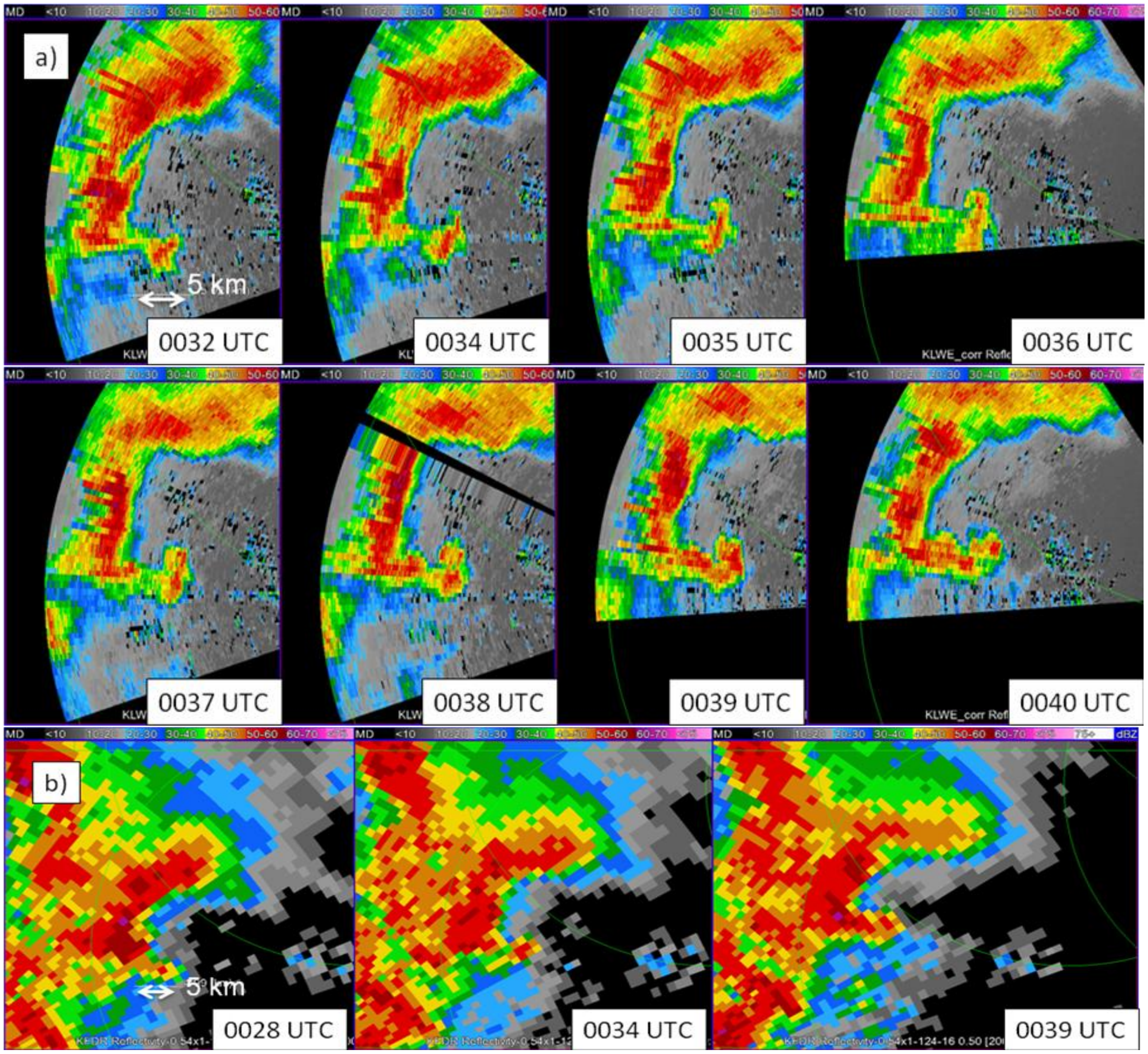

Figure 6: a) Time series of reflectivity data collected at 1.0 deg elevation from the CASA radar near Lawton (KLWE) between 0032 UTC and 0040 UTC 9 May 2007. b) Level 3 reflectivity data collected at 0.5 deg elevation from the WSR-88D radar near Frederick, Oklahoma (KFDR) between 0028 UTC and 0043 UTC 9 May 2007.

Another unique feature observed in the KLWE data is the presence of an anti-cyclonic circulation. Between 0030 UTC and 0041 UTC, a cyclonic – anticyclonic pair of circulations was observed in the lowest levels of reflectivity and velocity associated with the parent hook echo (Figure 8). In fact, during this time the strongest velocity signature was associated with the anti-cyclonic circulation. A series of reflectivity images at 2.0 degrees elevation (Figure 9) from KLWE shows the growth and decay of this anticyclonic shear region. Similar cases have been demonstrated in the literature (e.g., Brown and Knupp 1980; Rasmussen et al. 2006) and with the phased array radar of the National Weather Radar Testbed (Zrnic et al. 2007).

One unique feature of DCAS is the ability to do adaptive, sector scanning. Selectively scanning only the most “interesting” areas of the atmosphere reduces the need for time-consuming 360 degree scans. This methodology frees additional time that is used instead to scan the volume of a specific storm of interest, at a rate of up to once per minute. An example of this scanning technique, as shown in Figure 10, demonstrates the ability to collect one 360 degree azimuthal scan (at the 2 degree elevation) and seven 60 degree azimuth sector scans, all within a one minute time frame. An examination of this volume scan shows vertical continuity of the cyclonic - anticyclonic circulations from approximately 200 m AGL to as high as 3.5 km AGL.

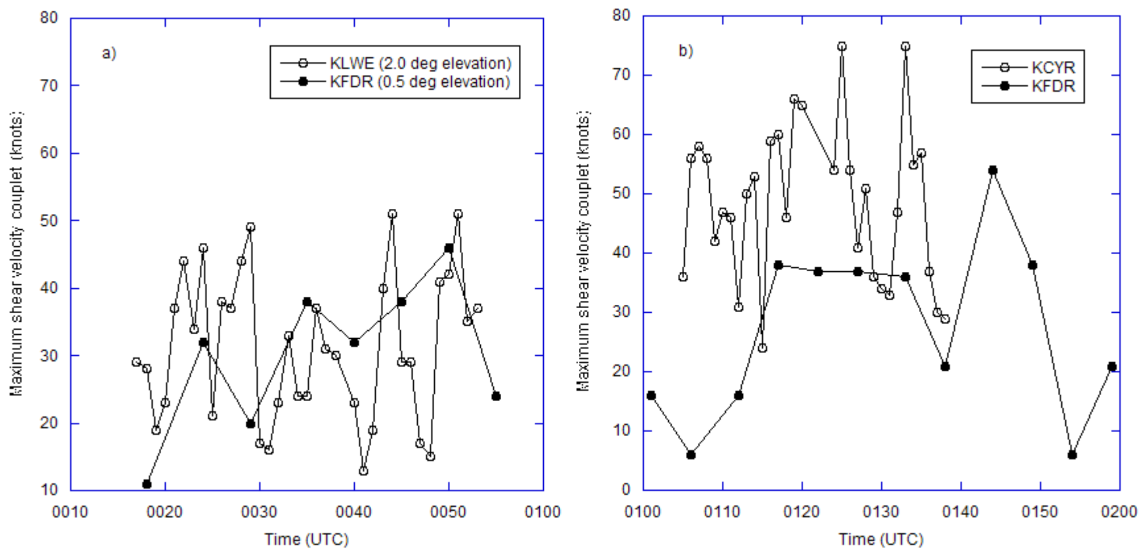

Figure 7: a) The maximum shear velocity couplet (knots) observed from KFDR and KLWE between 0015 UTC and 0055 UTC. b) The maximum shear velocity couplet (knots) observed from KFDR and KCYR between 0100 UTC and 0159 UTC.

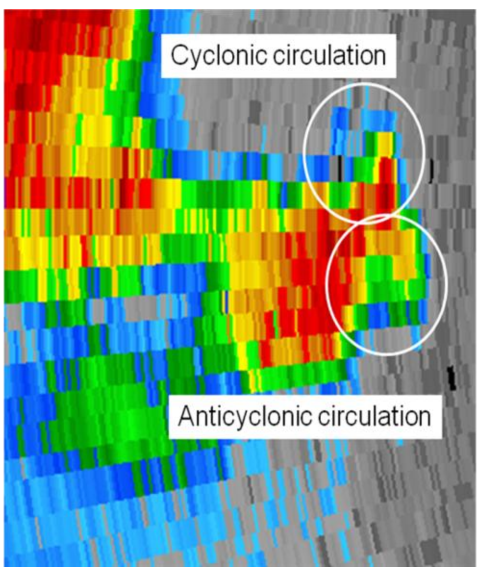

Figure 8: Reflectivity data collected at 2.0 degrees elevation from the CASA radar near Lawton (KLWE) at 003253 UTC 9 May 2007. Note the cyclonic and anticyclonic pair of ‘hook’ echoes.

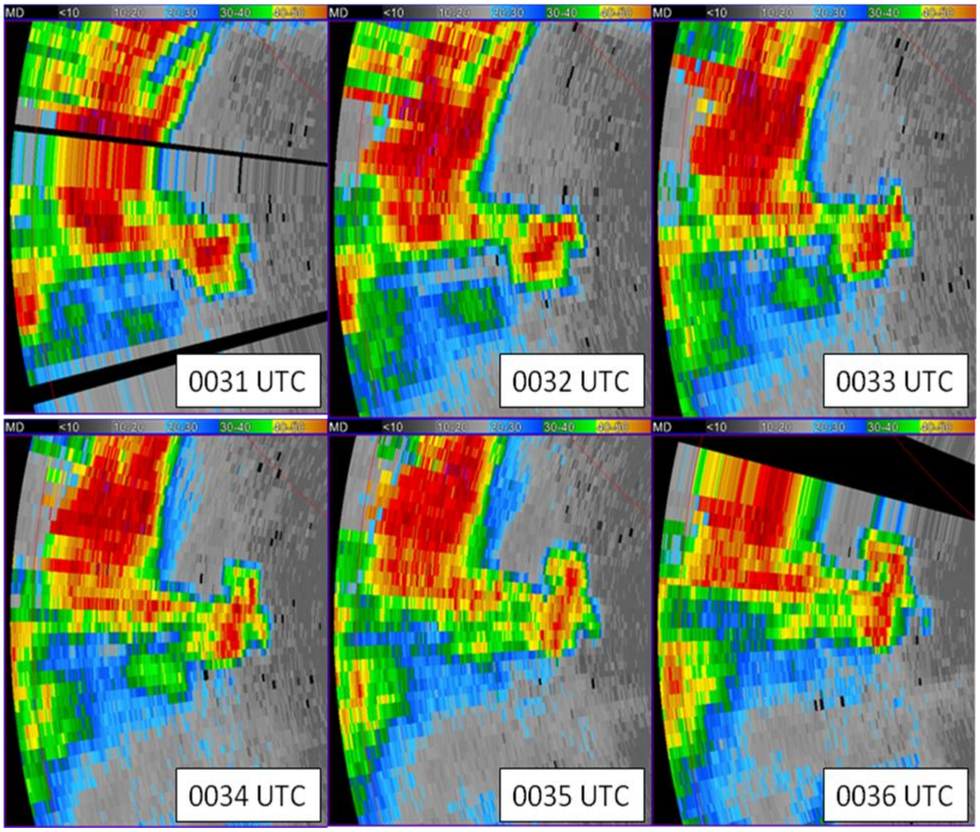

Figure 9: Reflectivity data collected at 2.0 degrees elevation from the CASA radar near Lawton (KLWE) at times 0031, 0032, 0033, 0034, 0035, and 0036 UTC on 9 May 2007. Note the cyclonic and anti-cyclonic pair of 'hook' echoes.

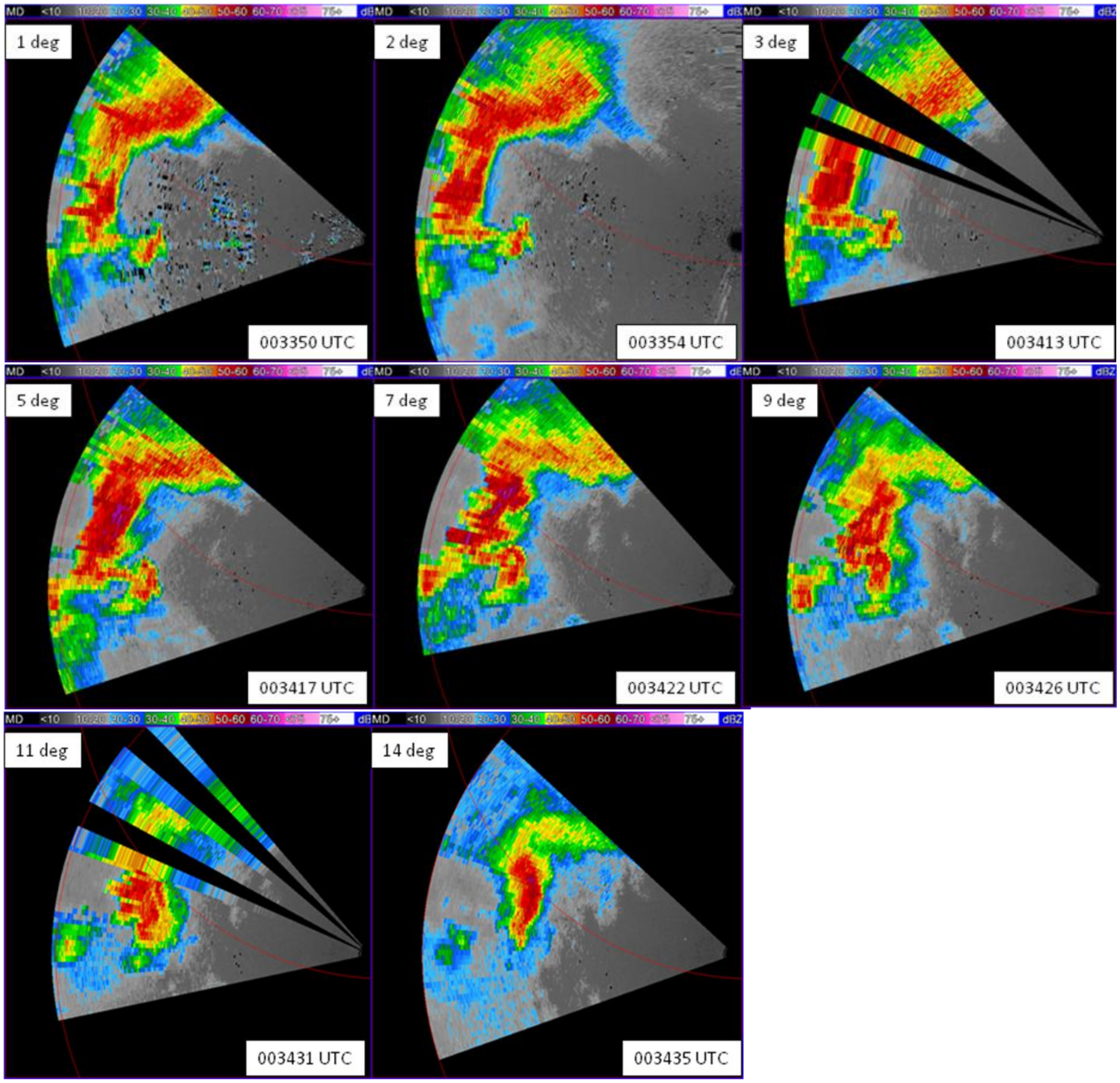

Figure 10: A demonstration of the adaptive, sector scanning capabilities. Reflectivity data collected at 1, 2, 3, 5, 7, 9, 11, and 14 degrees elevation at times 003350, 003354, 003413, 003417, 003422, 003426, 003431, and 003435 UTC, respectively.

DCAS also provides the ability to extract and display vertical slices from the volume scans (e.g., Figure 11). With volume scans collected every minute, rapid change can be monitored throughout the depth of the storm. Note that some attenuation is evident near the storm top in the vertical slice display of Figure 11.

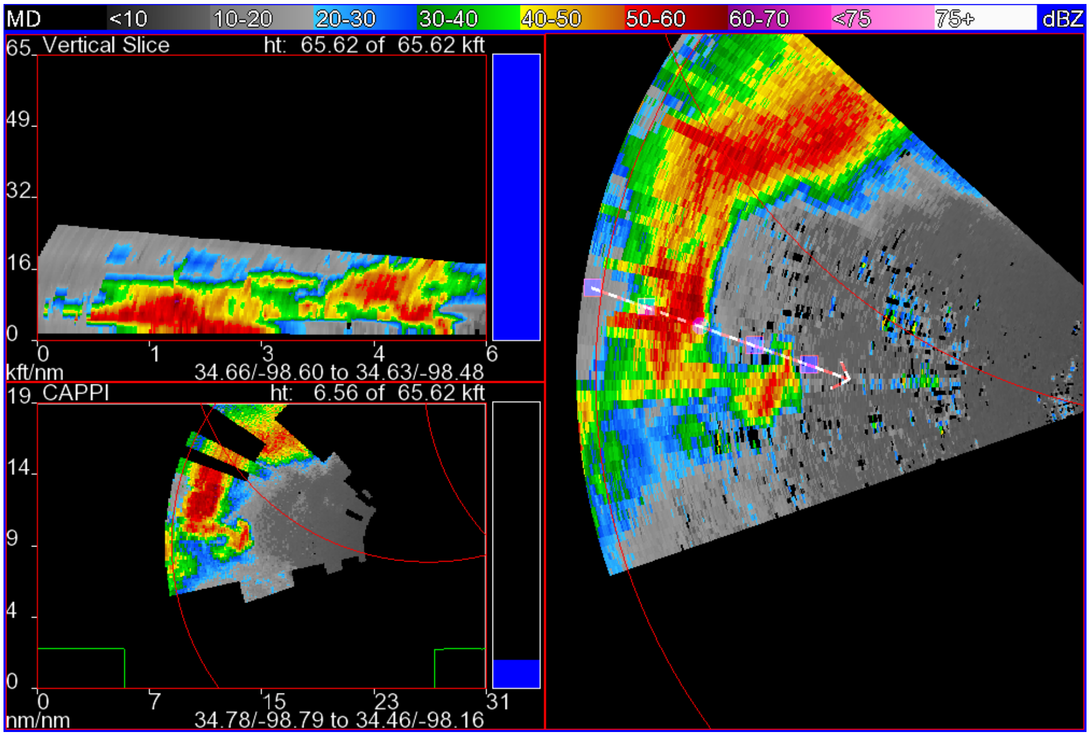

Figure 11: A vertical slice image created from the consecutive PPI slices. Because of the adaptive scanning capabilities, a full volume scan of the storm can be completed and displayed once per minute.

4.2 Minisupercells near Chickasha, 0300 – 0400 UTC

As the mesoscale vortex moved north, a series of mini-supercells developed beginning at 0300 UTC just to the west and north of the CASA radar near Chickasha (KSAO). At least three distinct circulation areas were identified between 0300 UTC and 0400 UTC within range of the KSAO radar. These circulations were compared directly as observed from the KTLX (WSR-88D) radar and CASA's KSAO radar. The KSAO radar distance to the circulation ranged from 16 km to 30 km, yielding a minimum scanning height of ~400 m to 1.1 km at the 2.0 deg elevation angle. The KTLX radar range was approximately 70 km, yielding a minimum scanning height of ~ 900 m at the 0.5 deg elevation angle.

The first circulation area formed at approximately 0300 UTC and was clearly observed in the velocity data from both KTLX and KSAO. For this case, the ability of the CASA radars to scan lower (and more frequently) than NEXRAD provides a much more accurate depiction of the storm progress and development (Figure 12). In this example, the circulation region, as observed by KSAO, is seen drifting to the west-northwest and dissipating by 0322 UTC. However, no such feature is observed with KTLX. Instead, a broad and persistent circulation area is observed moving to the north-northeast. This indicates that the CASA and WSR-88D radars are observing two separate features, and that the CASA system, with increased time and spatial resolution and its ability to observe below one kilometer, is capable of tracking phenomena that would otherwise not be detected.

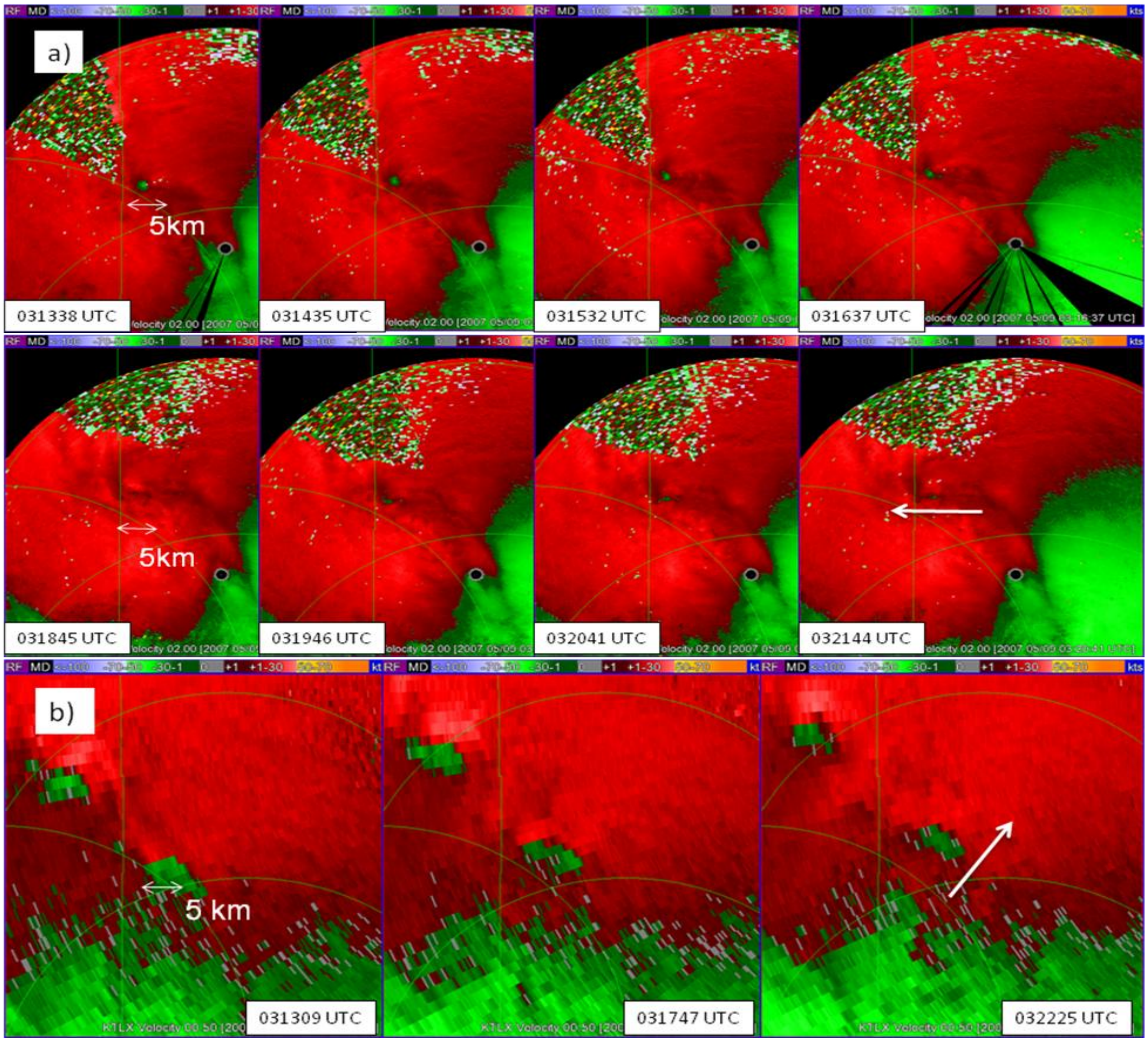

Figure 12: a) Velocity data collected from the CASA radar near Chickasha (KSAO) at 2 degrees elevation at times 031338, 031435, 03413, 031532, 031637, 031845, 031946, 032041 and 032144 UTC. b) Velocity data collected from the WSR-88D radar at Twin Lakes, OK (KTLX) at 0.5 degrees elevation at times 031309, 031747, and 032225 UTC.

A second circulation area forms directly to the north of KSAO by 0333 UTC (Figure 13a). Animation of the reflectivity and velocity from KSAO shows this feature to be a newly formed low-level vortex. However, data from KTLX shows only a single yet persistent shear couplet from 0313 UTC to 0341 UTC. Because of the differences in scanning height, the CASA radar is likely observing lower, smaller-scale vortices distinctly different than that observed by NEXRAD.

One clear disadvantage of the CASA system is attenuation, as noted by the speckled areas to the northwest of the shear signature (Figures 12a, 13a). In a much larger operational network, overlapping coverage from neighboring radars would be able to “fill-in” these gaps, and complete attenuation would be limited to the edges of the network domain.

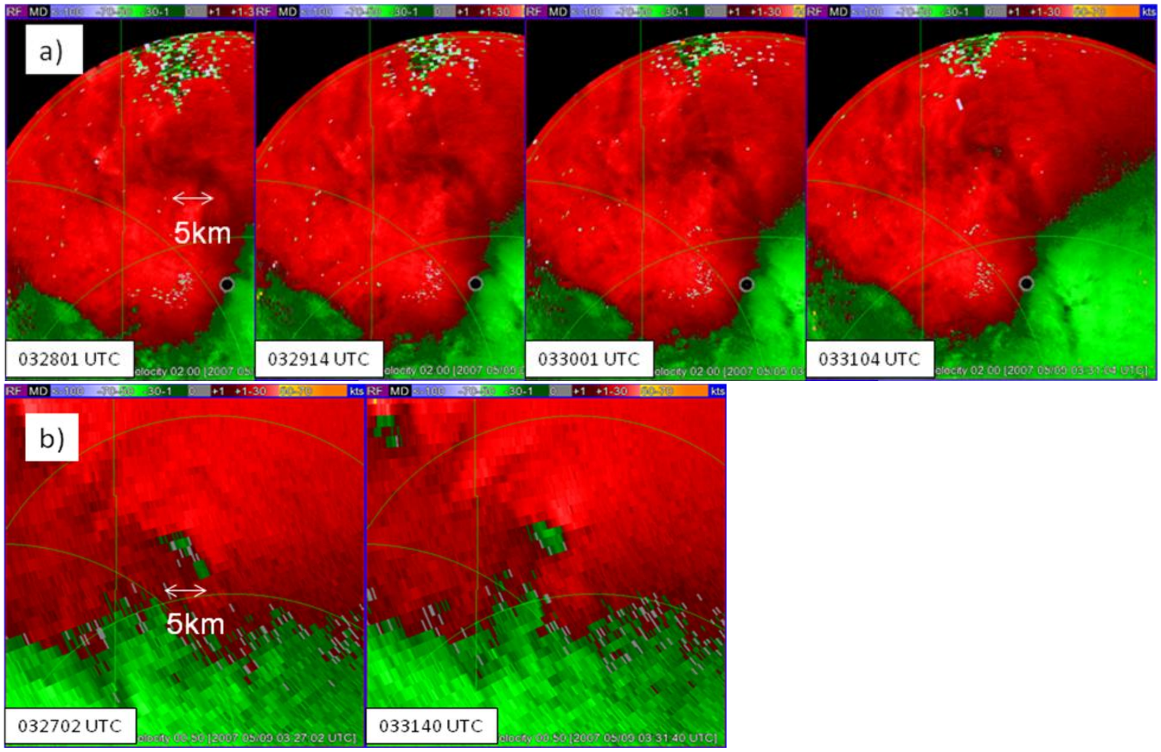

Figure 13: a) Velocity data collected from the CASA radar near Chickasha (KSAO) at 2 degrees elevation at times 032801, 032914, 033001 and 033104 UTC. b) Velocity data collected from the WSR-88D radar at Twin Lakes, OK (KTLX) at 0.5 degrees elevation at times 032702 and 033140 UTC.

5. SUMMARY

During 8 May 2007 an MCS moved north through the CASA testbed providing an excellent opportunity for evaluation of the DCAS scanning strategy. While no strong velocity shear features remained for long within the dual-Doppler region of the testbed, the DCAS strategy for scanning still proved beneficial for providing more focused volume scanning of the features of interest.

In part because of the DCAS strategy for scanning, several features were identified in the CASA data that were not observed from the WSR-88D data. A pair of cyclonic-anticyclonic shear couplets was identified in association with the supercell storm near Lawton, and rapid volume scans of the storm showed vertical continuity of these features. Low-level outflow from the supercell near Cyril was detected by KCYR minutes before it was observed from KFDR. The development and evolution of smaller scale vortices near Chickasha were identified and tracked, unable to be seen in the corresponding KTLX data. In fact, an entire class of vortices, unobserved by conventional means, are now resolved.

Overall, the much higher temporal and spatial resolution of the CASA data, when combined with the ability to scan lower in the atmosphere than existing S-band radars, yields a unique tool for capturing the time and spatial scales associated with miso- to mesoscale features of the atmosphere.

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