8A. 6 CASA IP1: NETWORK OPERATIONS AND INITIAL DATA

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1. INTRODUCTION

The Engineering Research Center for the Collaborative Adaptive Sensing of the Atmosphere (CASA) has a ten-year vision to create a collaborative, low-cost, dual-polarization, electronic scan radar network, designed to dynamically adapt in real-time to changing weather and end-user needs (McLaughlin et al., 2005). A series of testbeds, known as Integrative Projects (IPs), are being developed in order to demonstrate and test these new technologies. The goal of the first testbed, IP1, is to demonstrate and test distributed, collaborative, and adaptive sensing techniques, with an emphasis on detecting and tracking tornadoes and severe wind (Brotzge et al. 2005).

IP1 is comprised of four dual-polarization X-band radars located in southwestern Oklahoma (Fig. 1). The four radar network was installed by 1 May 2006, and associated signal processing, detection algorithms, and display software were installed during the summer of 2006; IP1 was fully functional by 1 August 2006. The four IP1 radars collaborate adaptively in real-time, with collective scanning strategies updated every 30-seconds as modified by rapidly evolving weather and end-user priorities. Data are transmitted in real-time to researchers, industrial partners, the National Weather Service (NWS), and emergency managers. The data are also made available for assimilation into numerical models. Optimal collaborative scanning commands are derived from a combination of output from data mining algorithms, end-user rules and numerical models, and are sent to the radar control processor in real-time. Figure 2 shows a holistic system architecture which demonstrates the high-level system operation and data flow.

The goal of this paper is to demonstrate operations of IP1 through the analysis of a severe storm complex that moved through the test bed area in the afternoon and evening of 15 August. It will address data collection and dissemination of data to users, weather feature detection, optimization and resource allocation. This case study will serve to present a detailed examination of IP1 operations, highlight the unique advantages of the CASA network, and showcase future additions to the system.

2. CASE STUDY

A nearly stationary east-to-west warm frontal boundary focused convection across the IP1 network during the afternoon and early evening of 15 August 2006. Isolated storm cells formed and moved north through the network from 2100 UTC 15 August to 0100 UTC 16 August. A second area of stratiform rain with embedded convection moved across the network from 0100 UTC to 0500 UTC. Total storm rainfall ranged from 0.5 cm to 2.0 cm as measured by the Oklahoma Mesonet sites within the IP1 network. The NWS issued one thunderstorm warning within the network for Grady County at 2130 UTC, and several severe wind reports were recorded just south of IP1 at approximately 0000 UTC.

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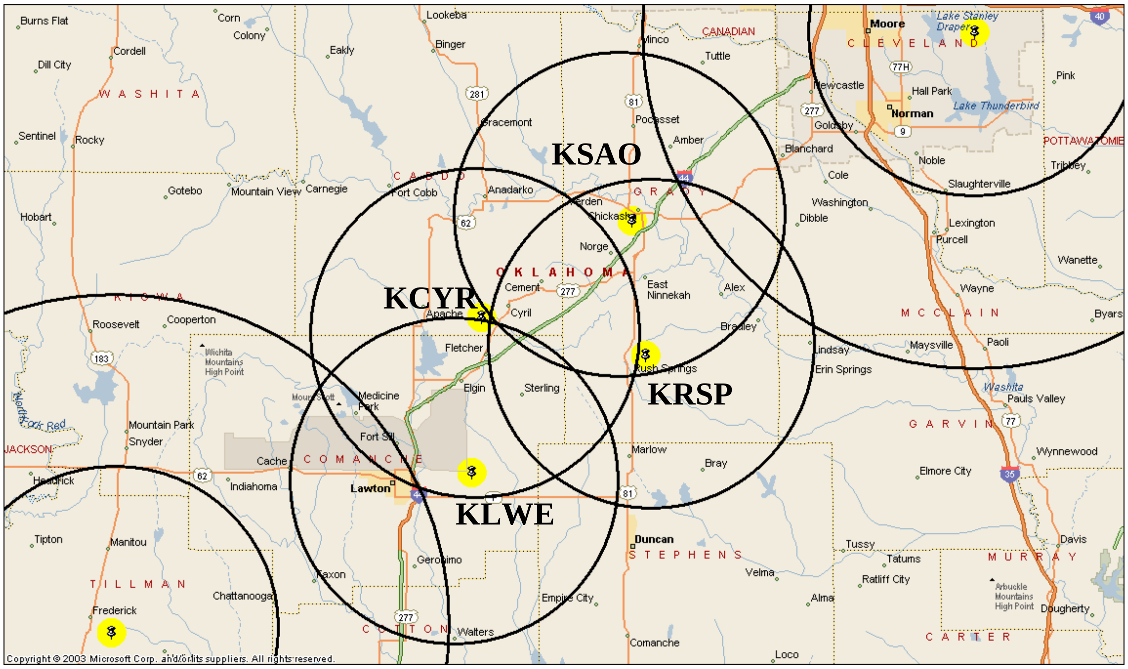

Figure 1: Geographic locations of four IP1 radars. Radar sites are located in or near the cities of Chickasha (KSAO), Rush Springs (KRSP), Lawton (KLWE), and Cyril (KCYR). Range rings of 30 km are shown. The nearest NEXRAD sites located near IP1 are the radars at Twin Lakes (KTLX) and Fredrick (KFDR) and are shown with 30 km and 60 km range rings.

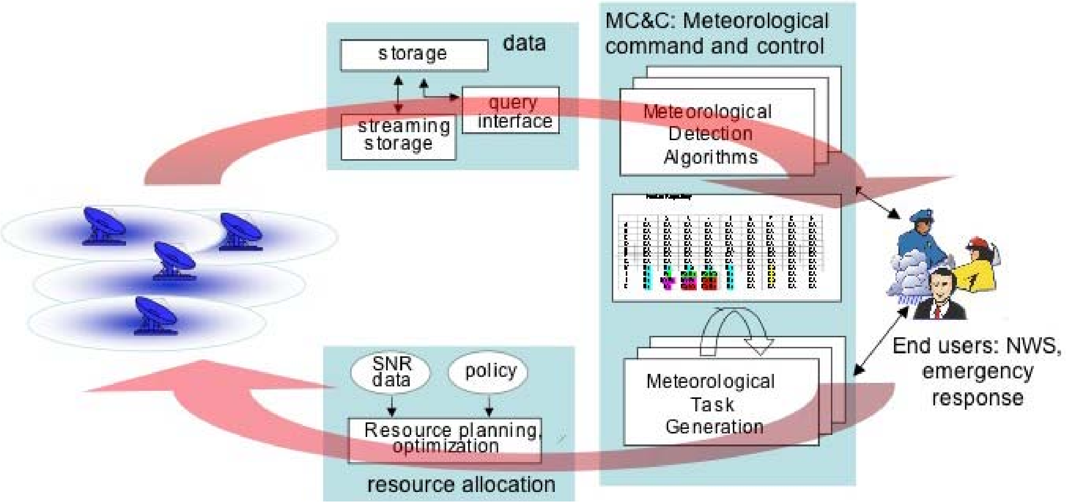

Figure 2: A simplified system architecture demonstrating the data flow within IP1. Figure courtesy of J. Kurose.

3. DATA COLLECTION

The IP1 network is comprised of four X-band magnetron-based radars (Junyent et al. 2005), spaced nearly equidistantly at about 25 km separation. The radar network is configured in such a way as to maximize dual-Doppler coverage while utilizing network connections of the Oklahoma OneNet system (Brewster et al. 2005). Each radar is dual-polarized, with single and dual-PRF capability, and is remotely configurable and controllable. Although the goal of CASA is to develop phased-array antenna radars, the IP1 radars have a parabolic antenna mounted on a pedestal capable of high speed acceleration to approximate the agility of a phase-array antenna. Each radar samples the received digital radar signals, and the Doppler moment data such as reflectivity and velocity are generated in real-time. The base variables include reflectivity, velocity, spectrum width, and the dual-polarization variables of ρ_{HV}, φ_{DP}, and Z_{DR}. A dual-polarization based technique was applied to single radar data to produce attenuation-corrected reflectivity and attenuation-corrected Z_{DR} (Park et al. 2005a, 2005b). Clutter mitigation and velocity unfolding algorithms are also implemented in the IP1 system. Key radar parameters are listed in Table 1, and further details about the radars can be found in Junyent et al. 2005.

Key System Parameters	
Operating frequency	9.3 GHz
Wavelength	0.03 m
Antenna Diameter	1.20 m
Antenna Beamwidth	1.8 deg
Antenna Gain	38 dB
Max radar scanning speed	35 deg/sec
Max radar acceleration	50 deg/sec^2
Maximum range	36 km
Range resolution	26 m
Effective Transmitter Power	12.5 kW
Average Transmitter Power	25 W
Dual Pulse Repetition Frequency	1.6kHz, 2.4 kHz
Noise Figure	5.5 dB
System Losses	-20 dB
Mean Sensitivity	2.8 dBZ

Table 1: Key radar parameters for IP1.

For the 15 August case study, three radars were operational, with the Lawton radar (KLWE) undergoing maintenance. All radars were operated in single PRF mode and were scanning at a rotation rate of 35 deg sec^{-1}. The attenuation correction algorithm was applied, but the clutter mitigation filter and velocity unfolding algorithms were not yet fully implemented. The radars were operated in “closed-loop mode”, meaning the radars responded in real-time to specific weather features as recognized by data mining software. Every 30-seconds, each radar was directed to scan in either two complete 360 deg scans at 3 and 4 degree elevations, or in repeated sector scans of up to 6 elevations at 3, 4, 7, 9, 11, and 14 degrees, based on user preferences defined by static rules.

4. DATA INGEST, ARCHIVAL, AND DISTRIBUTION

Single files of moment data are generated for each elevation scan at each radar node and are transmitted at a rate of ~ 25 Mb sec^{-1} via OneNet microwave tower network to a central location known as the Systems Operation Control Center (SOCC), located at the University of Oklahoma in Norman. The SOCC’s three dual-processor servers, each with 3 GB of RAM, are required to meet the computing demands of IP1 operations. For the 15 August case, over 30 hours of data were collected, generating nearly 72 GB of data and 8,250 files.

All moment data are archived at the SOCC with nearly 6 TB of on-line storage capacity. An additional 12 TB of data can be stored on-line using the SOCC’s tape archive library system. End-users, including private sector partners, the National Weather Service, emergency managers and researchers, have access to all moment data and derived products. End-users have access to the stored data through ftp and a web-based interface (Figure 3). End-users have access to the real-time data stream via the Integrated Radar Data Services (IRaDS; Droegemeier et al. 2005). Emergency managers have access to real-time visualization of the data via WeatherScope (Figure 4). WeatherScope (Wolfinbarger et al. 2004) is a GIS-based platform for displaying weather data specifically designed to facilitate emergency manger operations.

IP1 Integrative Project 1

What is IP1?

Integrative Project One (IP1) is the first end-to-end test bed of the National Science Foundation's Center for Collaborative Adaptive Sensing of the Atmosphere (CASA). IP1 is designed to connect end-users to a network of weather radars in the field to enable targeted sampling of the low-level (0 - 3 km) atmosphere. IP1 is comprised of four X-band (3 cm) radars, each with a beamwidth of 1.8 degrees and a range of 30 km.

KRSP, KLWE, KSAO, KCYR Now Operational!

The four radars of IP1, located at Chickasha (KSAO), Cyril (KCYR), Lawton (KLWE), and Rush Springs (KRSP) are now semi-operational. Each radar is still undergoing testing and calibration, but are now collecting data. All power, communications, and AC are now complete and operating. Attenuation correction and clutter mitigation software will be added during summer 2006.

Current Operational Status

Chickasha KSAO
Cyril KCYR
Lawton KLWE
Rush Springs KRSP

System Operation Status:

Radar Usage Schedule

Operational = white
Semi-operational = yellow
Maintenance = red
Experiments underway = blue

IP1 Radars

From left to right KSAO, KRSP, KLWE, and KCYR.

Figure 3: Web interface for IP1 end-users.

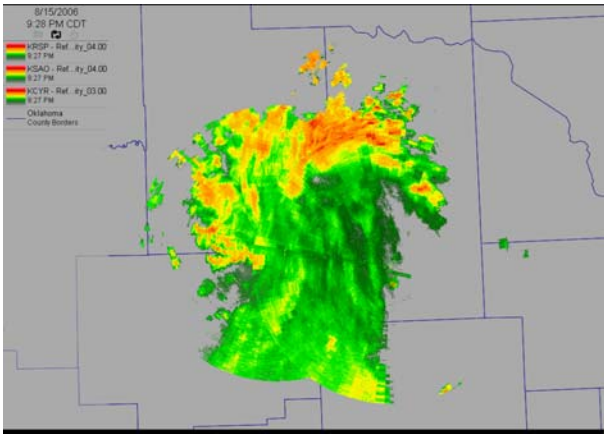

Figure 4: Reflectivity data collected from three IP1 radars (KCYR, KSAO, and KRSP) at 02:29 UTC 16 August as displayed by WeatherScope.

5. DATA PROCESSING

Real-time data streaming into the SOCC are ingested into a software framework known as the Meteorological Command & Control (MC&C; Zink et al, 2005, Pepyne et al. 2006). There are three primary components of the MC&C: 1) Feature detection algorithms; 2) Task generation algorithm; and 3) Optimization algorithm. Within the MC&C, all moment data are first ingested into the Warning Decision Support System – Integrated Information (WDSS-II; Hondl et al. 2007) suite of detection algorithms. The detection algorithms mine the CASA data stream, cataloguing features of interest such as areas of strong wind shear and high reflectivity. The detection algorithms provide feature information including feature type, location, and timestamp, and for some features the feature strength, direction of movement, and past and projected track are also provided. Reflectivity data from the four radars are merged together for mosaic display, and multi-radar velocity data are made available for dual-Doppler analysis. A sample merged reflectivity composite from 15 August is shown in Figure 5 as displayed by WDSS-II.

Output from the detection algorithms are summarized on to a blackboard architecture within the MC&C known as the "Feature Repository". Because of the gridded, GIS-based architecture of the system, CASA and NEXRAD radar, satellite, and surface data and model output can all be summarized into the repository, but for the 15 August case only the IP1 radar data were included.

Dual-PRF velocity was not available 15 August, so feature detection was limited to using only reflectivity. The 'EchoReflectivity' algorithm was the only feature detection algorithm available which operated exclusively on reflectivity. This algorithm identifies congruent areas of relatively high reflectivity. Output from the detection algorithm is displayed in the Feature Repository as square or polygonal shapes (Figure 6).

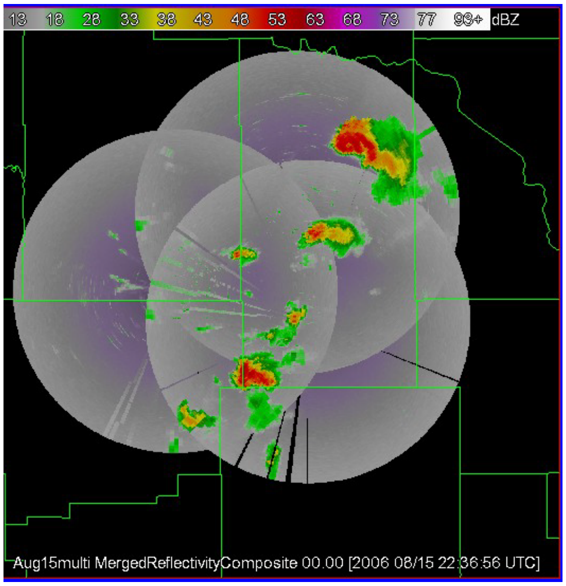

Figure 5: The merged reflectivity composite at 22:35:57 UTC.

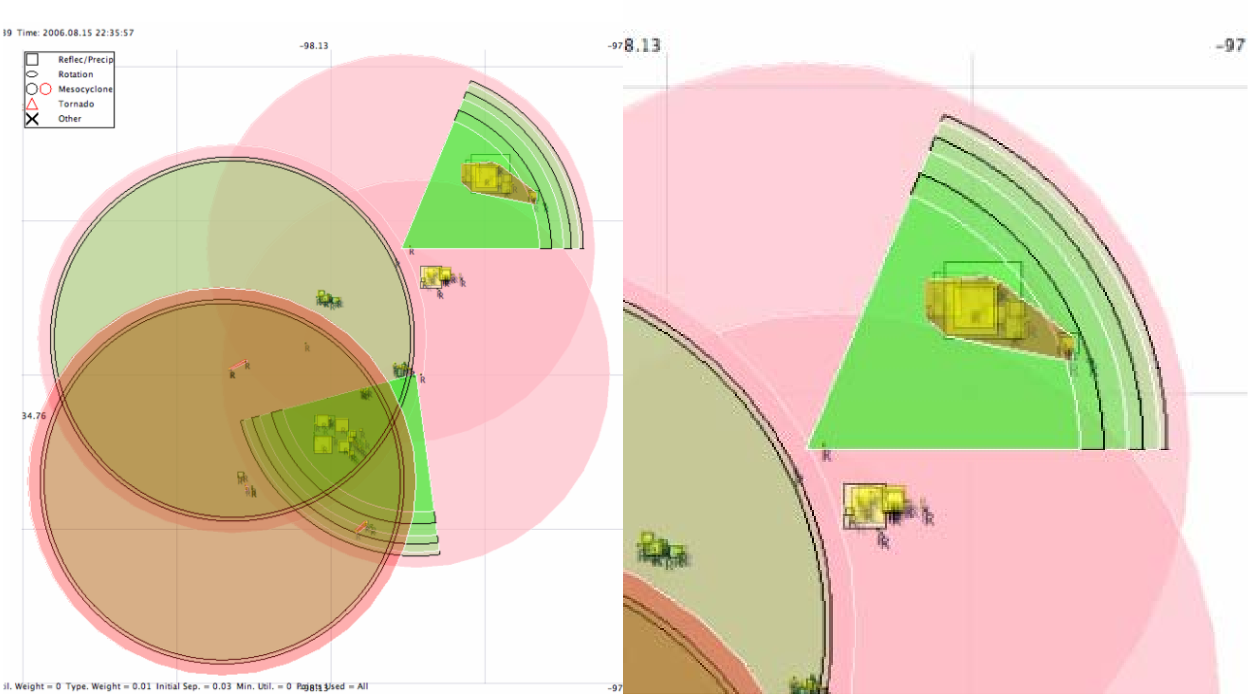

Figure 6: Visualization of the Feature Repository of data collected at 22:35:57 UTC. Weather features, for example, areas of significant reflectivity, are designated as yellow polygon shapes. Tasks are generated by clustering nearby areas of interest, and then scans are generated based on the features of interest and end-user needs. Final optimized scans are designated in green, with the rings on the edge of the sector denoting the number of elevation angles in the directed scan.

6. DATA OPTIMIZATION AND RADAR CONTROL

Next, scanning "tasks" are generated from the weather features that are identified within the repository. These tasks define areas of interest by clustering using similarity metrics such as Euclidean distance and feature type in areas with significant weather features. Each task defines the azimuthal scan, height, and number of radars required to fully scan the volume of interest (Zink et al., 2005). End-user rules are then used to determine the value (i.e., utility) for scanning each clustered area of interest [discussed in detail in Section 7].

A brute-force optimization method is used to turn each task into a specific radar command for each 30-second cycle. A list of sector configuration options is derived for each radar, each with a minimum sector size of 60 degrees. The total number of configuration options is limited to 30 per radar, yielding a total 810,000 possible network configurations per cycle. The utility of each scan configuration is calculated, and the single network configuration scanning pattern which provides for the greatest utility to end-users is chosen.

For the 15 August example shown in Figure 6, the final scan configurations are shown in green. The KCYR radar completed two 360 deg scans, while the KRSP and KSAO radars each completed 6 elevation scans each 60 deg in azimuth. The KRSP radar is nearest in proximity to the southern-most storm, and so the quantifiably best use of that radar's time, during the next 30-second cycle, is to do sector scanning on that particular storm. Likewise, KSAO is nearest the northern-most storm, and its quantifiably best use of its time, for satisfying the maximum number of end-users, is by doing sector scans of that particular cell. Meanwhile, the optimal use of KCYR is to continue to scan several widespread storm cells while monitoring for new development.

7. END-USER NEEDS

The IP1 system is designed for end-user needs to “drive” the data collection. Data are “pushed” to end-users in most data systems; however, IP1 features a data “pull” where user preferences drive the operation of the radars. These user preferences are stored as rules that are used by the resource allocation and optimization algorithms to determine which of the detected weather features are of interest to users and how these features should be scanned by the radars both temporally and spatially. Rules have been created for three different groups of users in IP1: National Weather Service forecasters, emergency mangers and CASA researchers. We anticipate that additional users, such as the media or private meteorology companies, will be added to CASA’s users.

Table 2 shows the current version of user rules. “Rule Trigger” indicates what activates a rule, which could be based solely on a time interval or detected weather feature. “Sector Selection”, “Elevations” and “ # of Radars” indicate the radar scanning requirements; and “Sample Interval” indicates the periodicity of the rule. The utility of a rule increases at it approaches its sampling interval.

For example, the NWS rule N2 indicates that storms (defined by high reflectivity) should be scanned, in a sector size that encompasses the edges of the storm at all elevations every 2.5 minutes. This rule addresses NWS forecaster needs to analyze vertical storm structures as they are determining whether to issue warnings. The Researcher Rule R3 executes a full volume scan every 5 minutes and reflects researcher needs for data to initialize numerical weather prediction models.

Rules associated with reflectivity (N1, N2, R2, R3, E1, E2 and O1) and triggered by the EchoReflectivity weather detection algorithm and time were functional during the 15 August event.

This list of end-user rules is being expanded in number and complexity as additional end-users are added, and as the needs of end-users are better understood (Philips et al. 2007).

Rules	**Rule trigger**	**Sector Selection**	**Elevations**	**# radars**	**Contiguous**	**Sampling interval**
NWS						
N1	time	360	lowest	1	Yes	1 / min
N2	storm	task size	full volume	1	Yes	1 / 2.5 min
Researcher						
R1	rotation	task size	full volume	2+	Yes	1 / 30 sec
R2	reflectivity	task size	lowest two	1	Yes	1 / min
R2	velocity	task size	lowest two	2+	Yes	1/ min
R3	time	360	all 7 every 15 min	1	No	1/ 5 min
Emergency Managers						
E1	time	360	lowest	1	Yes	1 / min
E2	reflectivity over AOI	task size	lowest	1	Yes	1 / min
E3	velocity over AOI	task size	lowest	2+	Yes	1/ 2.5 min
Operating System						
O1	time	360	lowest two	1	No	1 / 5 min

Table 2: End-user rules for IP1.

8. DISCUSSION OF AN EARLY DATA CASE

The end-goal of CASA is to produce a solid-state, electronic-scan radar network that satisfies competing end-user needs. IP1 demonstrates the use of DCAS – distributed, collaborative, adaptive sensing – as a means for achieving this goal. However, much work remains in quantifying the actual “added-value” of such a system when compared to existing radar networks such as NEXRAD.

A detailed study of the 15 August case demonstrates several advantages of IP1 over existing radar networks: 1) greater temporal resolution; 2) greater spatial resolution; and 3) radar collaboration and adaptive scanning.

Five-minutes of NEXRAD and IP1 data as displayed in WDSS-II are shown in Figures 7 and 8. Examination of the IP1 data reveals much greater storm structure in time and space than can be seen from the NEXRAD imagery; animated versions of the IP1 plots show rapid intensification and decay of storm cells. Single-cell development can be seen clearly in the IP1 data as shown in Figure 7; NEXRAD data also indicates some increase in reflectivity, but much less intense.

The collaborative and adaptive scanning (DCAS) enabled by the IP1 system design should permit more detailed observations. Collaborative scanning between neighboring radars allows for attenuation correction and dual-Doppler processing. Adaptive scanning allows for multiple cells to be tracked while alternately scanning for new cell development.

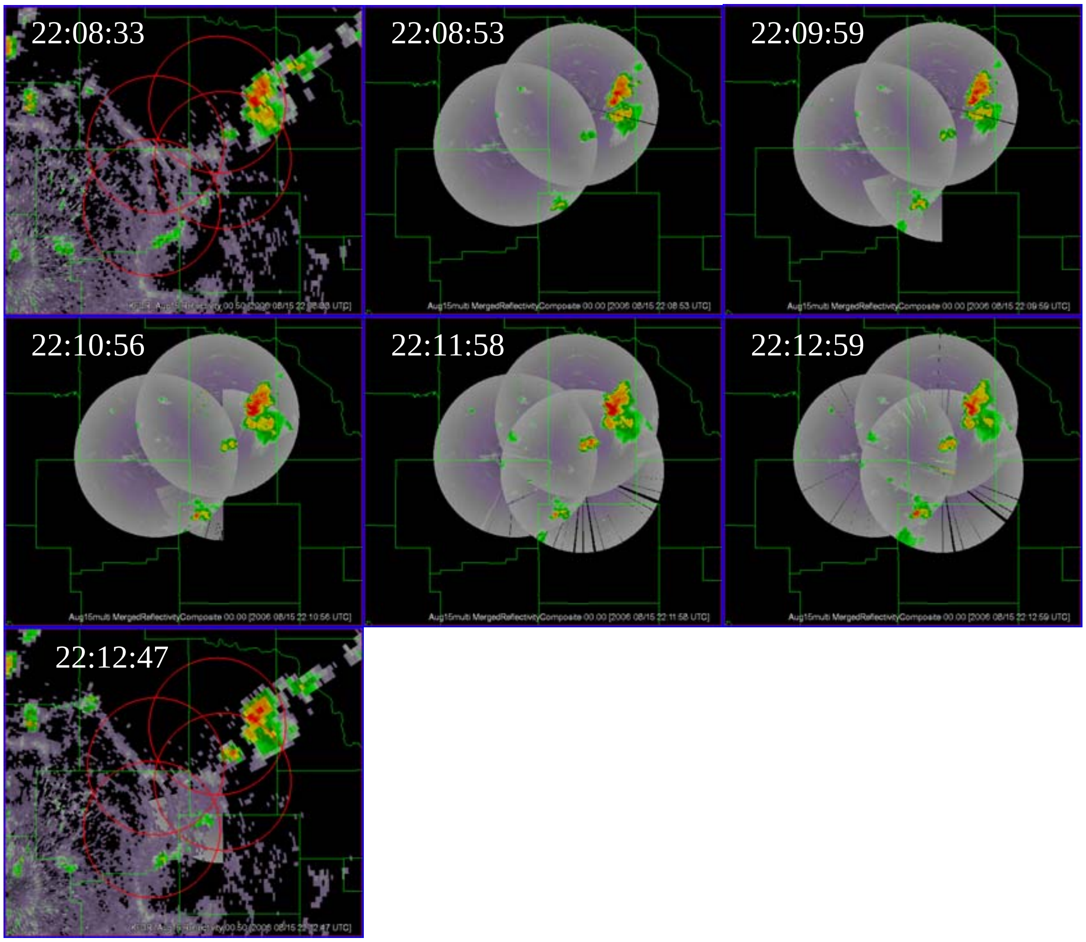

Figure 7: A comparison of NEXRAD and IP1 data collected 15 August during a 5-minute period from 22:08 UTC to 22:13 UTC.

In addition, the dynamic versatility of DCAS introduces some fault-tolerance to the network. When an IP1 radar becomes unavailable, neighboring collaborative radars simply adapt their scanning strategy to compensate.

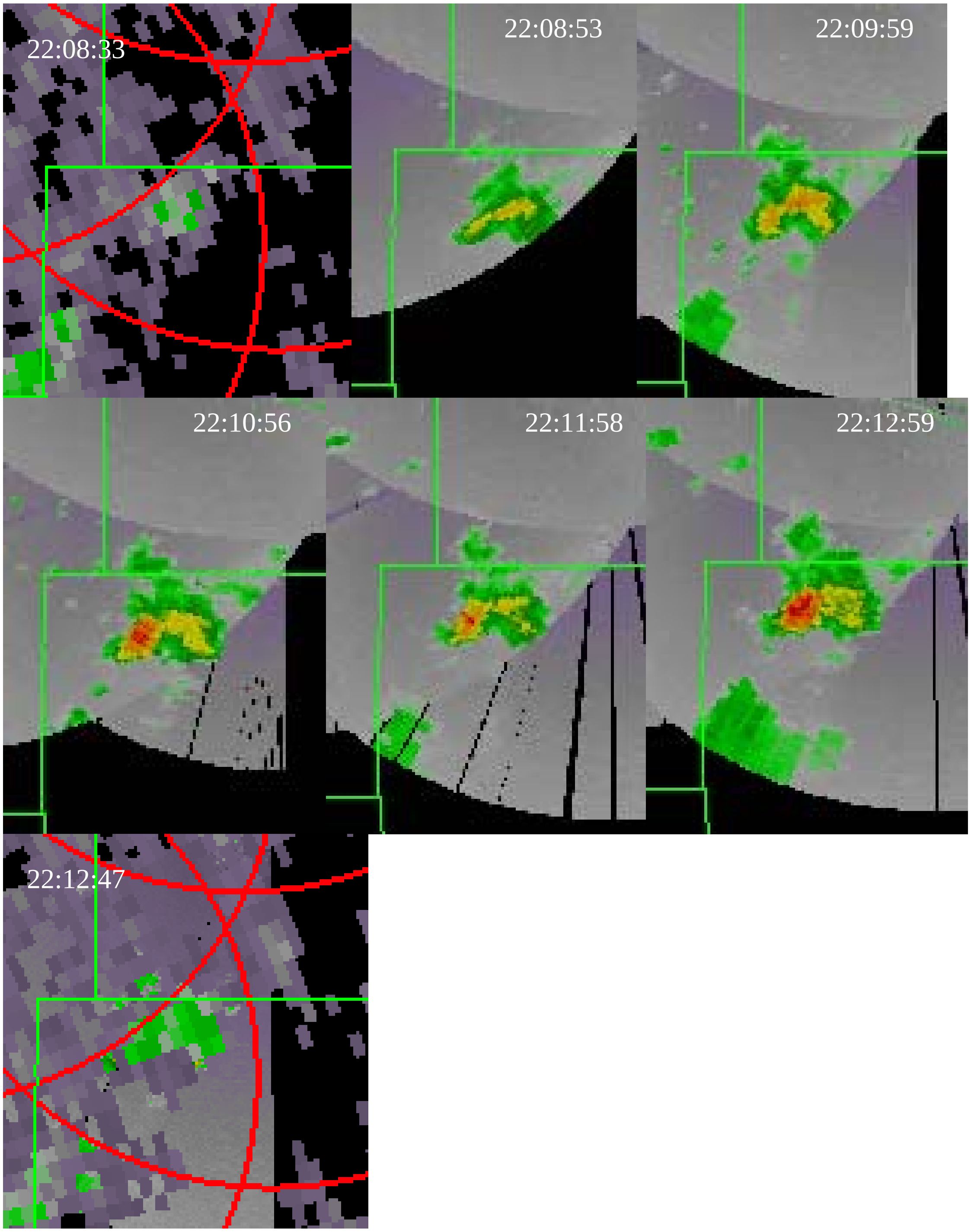

Figure 8: Close-up images of data as shown in Figure 7.

The advantage of DCAS is also demonstrated in the ability of the radar network to better observe and track developing features of interest, such as this example of a small cell near the southwest corner of Grady Co. at 2230 UTC (Fig. 9a). The Frederick NEXRAD radar was 90 km away, too far from this cell to see the same level of detail (Fig. 10). Although there was vertical continuity to the shear and evidence of a strong updraft with echo overhanging the low-level notch, examination of the CASA velocity data showed that the cell had some horizontal wind shear, but not strong gate-to-gate shear (Fig.9b). No tornado was reported with this cell and within 10 minutes the cell had lost much of its distinctive characteristics.

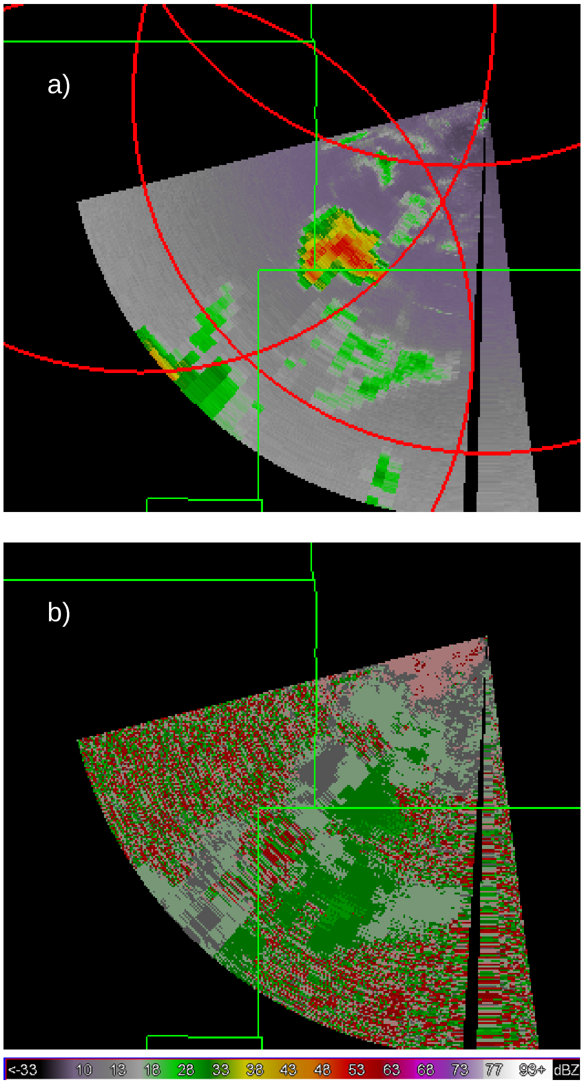

Figure 9: Radar data at 4.0 degrees from Rush Springs 22:32 UTC 15 Aug 2006. a) Reflectivity, b) Radial velocity.

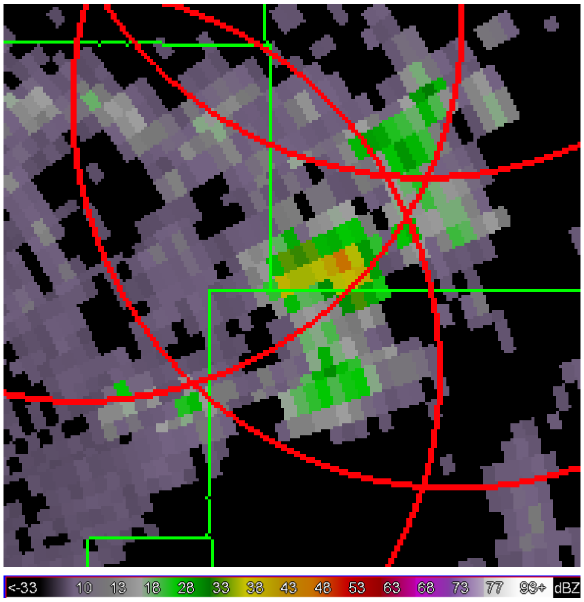

Figure 10: Radar reflectivity from NEXRAD, Frederick, Oklahoma, 22:33 UTC 15 August 2006.

9. SUMMARY

With the deployment of IP1, the CASA team has successfully integrated highly agile, dual-polarization X-band radars with attenuation-correction processing, long-distance networking, and a first-of-its-kind collaborative weather scanning system which is designed to meet the needs of end-users in central and southwest Oklahoma. As of this writing more sophisticated signal processing software is being installed on the radars, the rules for radar collaboration are being refined, and DCAS continues to evolve using more sophisticated detection strategies, more complex scanning modes and more complex weighting of end-user needs.

10. ACKNOWLEDGMENTS

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