P13.2 SPRING 2008 REAL-TIME PHASED ARRAY RADAR EXPERIMENT

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1. INTRODUCTION

The year 2008 is the 20th anniversary of the final design for the Weather Surveillance Radar-1988 Doppler (WSR-88D), a mechanically rotating S-band radar. The 1988 design milestone was preceded by a ~30-year effort focused on the research and development of Doppler weather radars (Whiton et al. 1998). Prior to its initial acceptance as a replacement radar technology in 1979, was the achievement of nearly 20 years of Doppler weather radar research (1960–1979) and the completion of the Joint Doppler Operational Project (JDOP: 1976–1978). The JDOP was an operational test of Doppler weather radar capabilities that illustrated significant improvement in the accuracy of severe weather warnings and the lead time of tornado warnings (Burgess et al. 1979). Twelve years later, these demonstrated advancements in severe weather warnings began to become an operational reality with the installation of the first WSR-88D in Norman, Oklahoma. By 1997 the complete network of 158 WSR-88Ds was installed (Whiton et al. 1998).

Continuous improvements to the WSR-88D system hardware and products (e.g., Crum et al. 1998; Serafin and Wilson 2000) have resulted in significant service improvements, including increased mean warning lead time for tornadoes from 6 to 13 minutes, and reduced tornado-related injuries (40%) and fatalities (45%; Simmons and Sutter 2005). To maintain state-of-the-art weather radar capabilities, the dual-polarization upgrade to the WSR-88D network is on the horizon. Like DJOP, the Joint Polarization Experiment (JPOLE) illustrated new capabilities to improve operational services, in this case areal rainfall estimation, heavy rainfall measurements, and classification of meteorological and nonmeteorological echoes (Ryzhkov et al. 2005; Scharfenberg et al. 2005).

The approach of the WSR-88D system toward its 20-year design life cycle (Zrnić et al. 2007), continuous advances in radar technology, and the lead time involved in the research, development, acquisition, and deployment of new systems have motivated the consideration of a replacement system or family of systems (National Academies 2002, 2008). A replacement technology currently under consideration is phased array radar (PAR). PAR technology, employed for decades by the Department of Defense to track aircraft and other airborne targets, is now being examined to assess not only its weather surveillance capabilities (Zrnić et al. 2007; Heinselman et al. 2008), but also its capability to provide simultaneous weather and aircraft surveillance, termed multifunction phased array radar (MPAR; OFCM 2006; Weber et al. 2007).

An essential component of the research and development of this potential replacement technology is evaluation of its operational benefits by radar users. As discussed by Morss et al. (2005), incorporating user needs at the beginning and throughout the research and development process is pivotal to producing the most usable scientific knowledge or information. Morss et al. (2005) call this user inclusive, iterative process "end-to-end-to-end" research.

The National Weather Radar Testbed (NWRT), located in Norman, Oklahoma, provides the infrastructure needed to explore the potential benefits of this experimental technology to forecast operations. The unique features of PAR

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technology are the capabilities to rapidly and adaptively sample storms electronically from an S-band antenna at time scales of seconds instead of several minutes (Zrnić et al. 2007). The operational need for rapid scanning is supported by responses to a recent questionnaire on volume coverage pattern (VCP) usage by NWS forecasters, which was conducted by the Radar Operations Center (ROC; Steadham 2008). The study shows that 62% of respondents (N=80) voiced a need for faster scanning than is currently available. Within this group of respondents, more frequent low-elevation scans (37%) and faster VCPs (25%) were specified as the most important scanning strategy improvements. Similarly, a study on the critical strengths and limitations of current radar systems by Newman et al. (2008) find that both NWS forecasters and broadcast meteorologists in the Southern Plains believe it is important have rapid scanning capability to detect and warn on small-scale weather hazards that develop on short time scales. Furthermore, a recent study of severe storms sampled by the NWRT PAR and the WSR-88D show that volumetric, high-temporal sampling by PAR (≤ 1 min) provides improved depictions of rapidly evolving weather phenomena (Heinselman et al. 2008).

To evaluate the operational benefits of this experimental technology, 19 forecasters from 17 NWS Forecast Offices participated in the 2008 Spring PAR Real-time Experiment, which ran from 28 April–6 June 2008. During each week (Monday – Thursday, 1 pm–9 pm CDT), on average 3–4 NWS forecasters participated in this experiment as a part of the Experimental Warning Program (Stumpf et al. 2008). The purpose of this paper is to report on the experiment's design and preliminary findings.

2. PAR DATA COLLECTION

The 2008 Spring PAR Real-time Experiment was designed to collect high-quality data sets for basic research studies and assessment of the operational utility of rapid-update PAR data. To collect high-quality data with high-temporal resolution, two enhanced VCP-12 scanning strategies were developed (Table 1). The enhanced VCP 12 scan strategies took advantage of the operational VCP 12's range and accuracy characteristics (Brown et al. 2005; ROC 2007) while improving vertical sampling. Vertical sampling was optimized based on whether storms were near or far (70-km threshold) from the radar, and temporal sampling was optimized at low-levels by revisiting the 0.5° tilt on average every 23 s. Both the near and far scanning strategies volumetrically sampled a 90° sector within about one minute (61 s); a four-faced PAR system would scan four 90° sectors (i.e., 360°) within the same period. When needed, these scan times could be cut in half by running the enhanced VCP 12 scan strategy over a 45° degree sector. The result was ~12 s updates of the 0.5° tilt and ~30 s volumetric updates.

During the experiment, five weather events occurred while participants were on duty (Table 2). These weather events included a few tornadic supercells, a squall line and mesoscale convective vortex with tornado development, storm development along a cold front, and nontornadic supercells. Throughout these events, forecasters evaluated the PAR data according to the guidelines described in section 3.

3. EVALUATION

Forecasters were asked to evaluate the operational utility of PAR data during both real-time data collection and simulated playback of archived weather events. Playback weather events were an important component of the evaluation for several reasons. First, in most cases they provided a data set to help familiarize forecasters with PAR data prior to real-time operations. Second, these events assured the opportunity to evaluate PAR data even if severe weather did not occur during the participant's week. Third, the playback data included weather events prevalent outside of Oklahoma and the Southern Plains to help forecasters experience how PAR may impact their job, in their forecast area. Finally, using playback data ensured a larger sample size than would be available from most real-time events. The larger sample size would potentially provide a broader, more complete perspective on the

Table 1. Elevation angles used in the Near (≤ 70 km-range) and Far (> 70 km-range) Enhanced VCP-12 scanning strategies. For both scanning strategies, volumetric scans run over a 90° sector are completed in 61 seconds. To improve azimuthal resolution, data were collected using 1° overlapped sampling.

Near Scanning Strategy	**0.51**	**1.5**	**2.6**	**3.8**	**5.2**	**6.8**	**8.7**	**0.51**	**11.0**	**13.8**	**17.2**	**21.3**	**26.2**	**32.0**	**38.0**
Far Scanning Strategy	**0.51**	**1.1**	**1.7**	**2.4**	**3.2**	**4.1**	**5.1**	**0.51**	**6.2**	**7.4**	**8.7**	**10.1**	**11.7**	**13.5**	**15.5**

Table 2. Real-time weather events and number of responses to questionnaire.

Date	Event	Number of Responses
1 May 2008	Multiple supercells, with tornadic supercells in Oklahoma, Payne, Pawnee, and Osage Counties	1
7 May 2008	Squall line and mesoscale convective vortex with tornado development over north-central Oklahoma	3
13 May 2008	Storm development along a cold front; some storms produced hail	2
22 May 2008	Supercell located initially in far western OK that eventually moved across north central OK; produced large hail	5
27 May 2008	Isolated storms in far southwest and western Oklahoma; produced hail and damaging winds	1

plausible benefits and limitations of the experimental PAR data.

The two playback events were 10 July 2006, a day with microbursts volumetrically sampled by the PAR every 34 s, and 19 August 2007, a day with low-topped tornadic supercells volumetrically sampled by the PAR every 43 s. Seven evaluations were attained for the microburst case, and ten were attained for the tornadic low-topped supercell case. Note that these sample sizes were at least twice those attained from most real-time events (Table 2). An exception is 22 May 2008, when a record 5 forecasters were available to evaluate the PAR data in real time.

In both the real-time and playback situations, forecasters were asked to analyze the data and issue warnings as they would in their job. The on-the-job mindset was encouraged to ensure that forecaster evaluations of PAR data took place in a quasi-operational environment. Following the real-time or playback weather event, forecasters were asked to respond to a nine-question survey designed to assess:

- strengths and limitations of PAR data, compared to WSR-88D data,
- how characteristics of PAR scanning strategies affected their interpretation of severe storms,
- how using PAR data to make warning decisions impacted the warning decision process, and
- how PAR data may be of benefit to operational responsibilities.

The survey questions were also designed to attain 1) specific information about the forecasters' experience of using PAR data during simulated warning operations and 2) to acquire their thoughts about their operational radar needs and potential improvements to service that may emerge from PAR technology.

The next section explains the methodology used to analyze responses to the questionnaire and shares preliminary findings. To date, a detailed analysis of the playback weather events has been completed and the analysis of the 2008 real-time events is in progress. Hence, only findings from forecaster evaluations of playback cases are discussed.

4. ANALYSIS METHODOLOGY AND PRELIMINARY FINDINGS

Since the questionnaire contained mostly open-ended questions, a data-driven thematic qualitative analysis method was employed (Boyatzis 1998; Patton 1990). The qualitative analysis was completed by coding written responses and then looking for themes among those codes. This analysis process was applied to each set of responses associated with each of the playback weather events. The themes that emerged from each event are discussed next.

4.1 MICROBURST

Seven forecasters evaluated the use of PAR and WSR-88D data following their simulated operational experience with a microburst event. A central theme that arose from the seven responses to the questionnaire was *benefits of high-resolution temporal sampling*. Words used by three different forecasters to describe their data interpretation experience with PAR data were "very useful", "valuable", and "extremely helpful." These word choices represented their capability to identify key precursors to microburst development and subsequently monitor their evolution. The structural features noted by forecasters were updraft development and intensification of the reflectivity core aloft, descending high-reflectivity cores, divergence couplets associated with downdrafts, and the evolution of strong winds near the surface (Fig. 1).

An important component in the analysis of microbursts is assessing the magnitude of the wind produced near the ground. Following the analysis of this microburst event, one forecaster remarked that, "High temporal resolution of PAR [data] allowed me to identify near-ground-level severe winds which were considerably under-played by KTLX: 27 kt vs 57 kt." Though in this case the higher radial velocity attained from the PAR was due, in part, to closer sampling of the storm (~20 km), sampling more frequently provides the opportunity to better sample maxima in the velocity field.

Forecasters also noted the benefit of a few minutes additional lead time in the warning of high winds from microbursts, owing to the capability to detect developing cores aloft earlier, and faster detection of features after they are sampled by the radar. Due to the relatively fast evolution of microbursts, and the current 4–5 min sampling of the WSR-88D, one forecaster stated that rapid updates "will help get the warning out period." Similarly, another forecaster said that the rapid sampling of PAR "would definitely help us to improve pulse storm warnings. We have many missed pulse storm hail and wind warnings."

Although all forecasters rated their confidence in making warning decisions using PAR data as moderately high (gave rating of 5, with 6 being the highest rating), three forecasters specifically expressed feelings of increased confidence during the simulation. These forecasters indicated that feelings of increased confidence arose due to their improved capability to interpret radar signatures and make decisions about whether or not to issue a warning. One forecaster described this experience as follows, "You can diagnose better what's going on so you can have more confidence in issuing or not issuing warnings."

Responses to the questionnaire also elicited specific recommendations from forecasters regarding scanning strategy needs for microbursts. Scanning strategy needs mentioned were fast update rates, scanning strategies with elevation angles adapted to better sample storms based on their distance from the radar, more near-surface sampling (i.e., below 0.5°), and rapid subsector scanning interspersed between basic scanning of the whole volume.

4.2 LOW-TOPPED SUPERCELL

Ten forecasters evaluated the use of PAR and WSR-88D data following their simulated operational experience with a tornadic, low-topped supercell event. Like the microburst case, a central theme that arose from forecaster responses to the questionnaire was *benefits of high-resolution temporal sampling*. All forecasters reported that the 43-s volumetric sampling by the PAR provided depictions of supercell storm structure and evolution superior to the WSR-88D's 4.1 min updates. They also found that the rapid updates resulted in quicker analysis of the development of circulations, including the rapid development of a short-lived tornadic vortex signature.

For seven of the ten forecasters, these improvements to operations produced feelings of increased confidence during their data analysis and/or warning decision making that they shared in their written responses. For instance, one forecaster stated, “PAR allows for increased confidence of storm feature evolution”, while another said, “All warnings were high confidence.” As a group, forecasters rated their confidence in making warning decisions using PAR data as moderately high or high (gave rating of at least 5, with 6 being the highest rating). During the simulated warning operations, however, only eight of the ten forecasters recorded their warning information. Based on analysis of the PAR data, these eight forecasters issued a tornado warning on the storm about 3 min prior to the storm’s development of an EF0 – EF1-rated tornado. Since a tornado vortex signature was sampled only once by the WSR-88D, it is unsurprising that a tornado warning was not issued during actual operations (Fig. 2).

Responses to the questionnaire also elicited specific recommendations from forecasters regarding scanning strategy needs for low-topped supercells. Five of the eight respondents voiced a need for rapid updates at low elevations. One specific suggestion was to “double [the] number of low-level tilts; attain [them] about every 1-min; upper tilts every 3 min.” Another was to attain rapid updates of the lowest three tilts to “assess vertical continuity in wind/tornado situations”, while sacrificing data collection at higher tilts. The need for rapid updates at low-elevation angles voiced by participants agrees with findings from a recent survey conducted by the Radar Operations Center on scanning strategy improvements needed by National Weather Service forecasters (Steadham 2008).

In their responses to the questionnaire, forecasters also provided feedback on initial challenges they think they would face if the current WSR-88D network was replaced with a network of PARs. A common theme voiced by forecasters was the idea that experience in analyzing rapid update data and making warning decisions from that analysis would be needed to “recalibrate” their warning decision process. A few forecasters explained that to recalibrate their warning process, they would need to gain experience as to how many consecutive scans needed to be examined prior to issuing a warning. In his own words, one forecaster explained, “Forecasters are typically trained to wait a couple of scans to see if [a feature] is persistent or real… [I] may need to wait 4–6 scans on PAR.”

Several individual operational concerns were also noted by forecasters. Feeling overwhelmed by the 43 s update rate in this playback case, one forecaster shared his desire to have control over the update rate shown on the radar display**.** Another forecaster speculated that warning sectors would need to be made smaller and WARNGEN functionality better, to handle fast evolving hazardous weather situations. A different perspective given by another forecaster was that in this case, the higher temporal resolution of the data, and increased probability of detecting precursors to hazardous weather, raised the number of warnings he issued. Although he had high confidence in all of these warnings, he was concerned about the societal impact of the potential increase in information to the public. Though an interesting and relevant question, answering it is beyond the scope of this study.

5. SUMMARY

As noted in the Introduction, this paper provides an overview of the 2008 Spring PAR Real-time Experiment and information about forecasters experiences with PAR data during two playback cases: a microburst and tornadic, low-topped supercell. The playback cases gave forecasters the opportunity to use and evaluate PAR and WSR-88D data in a simulated operational environment.

During each case, forecasters were asked to interpret the radar data and issue warnings as they would in their offices. Through this experience, all forecasters found the high-temporal resolution data beneficial to operations. Benefits experienced during both cases were the capability to identify earlier, and with more confidence, key precursors to hazardous weather development and their subsequent evolution. Forecasters also felt very confident in the warnings they issued, and said that using the PAR data allowed them to extend warning lead times.

In the near future, the analysis of forecaster responses during real-time operations will produce a more comprehensive study of the potential operational benefits of PAR.

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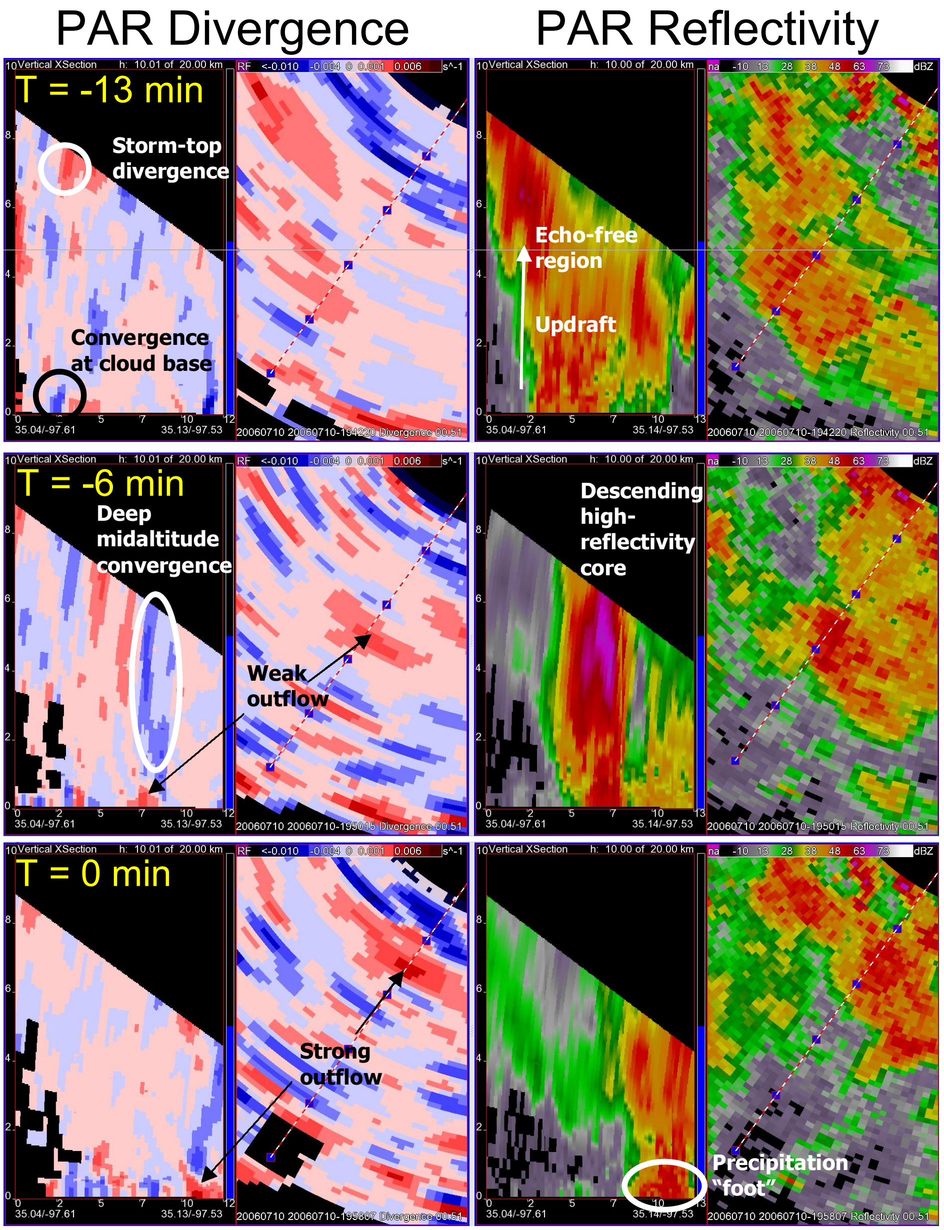

Figure 1. Key velocity and reflectivity structures detected and monitored by forecasters during the playback of the 10 July 2006 microburst event. The left column shows a vertical cross section and 0.5° elevation scan of the divergence field, derived from the radial velocity at 13, 6, and 0 minutes prior to the 30 m s^{-1} winds produced by the microburst. Red regions indicate divergence whereas blue regions indicate convergence. The right column shows the reflectivity field at the same times. Image courtesy of Travis Smith.

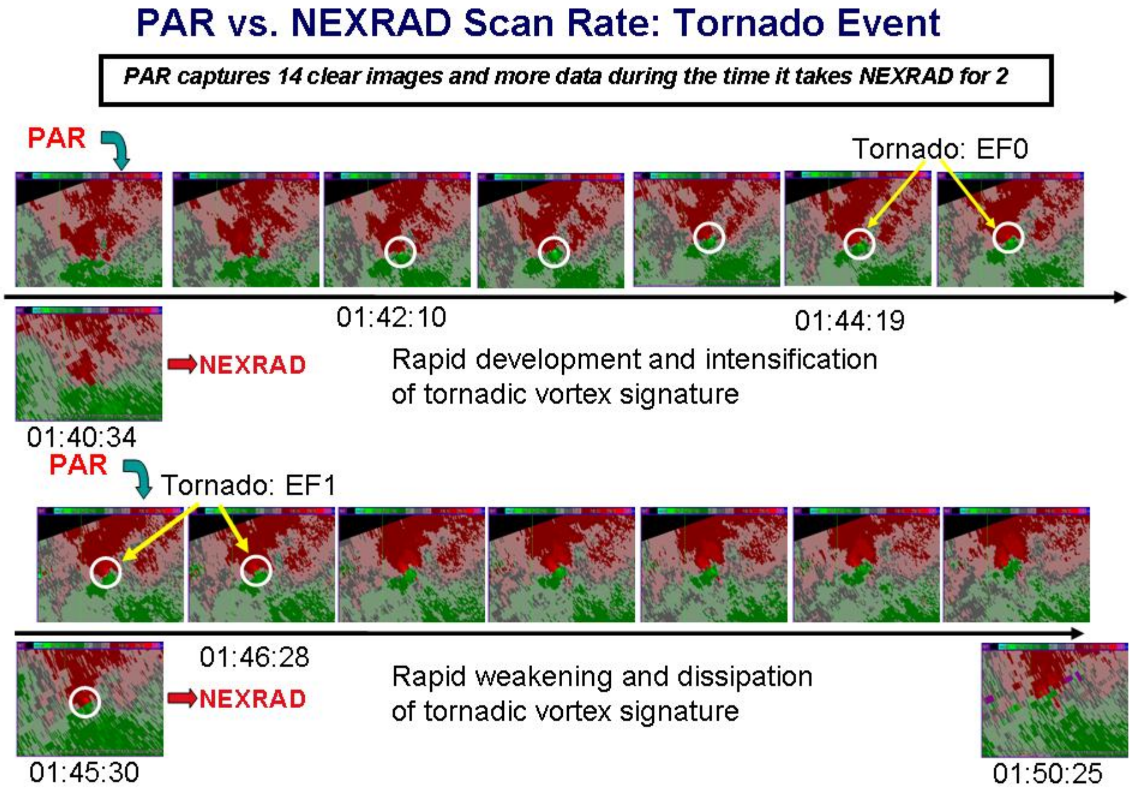

Figure 2. A 10-min time series (UTC) of 0.5° velocity data sampled by the PAR and the Oklahoma City NEXRAD (KTLX) on 19 August 2007. These images show the rapid development and intensification of a tornadic vortex signature indicative of a tornado that is sampled by PAR several minutes prior to NEXRAD. The green pixels indicate radial velocities toward the radars, whereas red pixels indicate radial velocities away from the radars. The NEXRAD radar is located 20 km northeast of the PAR.