5.7 Spring 2007 National Weather Radar Testbed Demonstration

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1. INTRODUCTION

The National Weather Radar Testbed (NWRT), located in Norman, Oklahoma, collects data from a 9.4-cm, single-faced, phased array antenna that supports adaptable scanning strategies and volumetrically scans a storm in time scales of seconds instead of several minutes (Zrnic et al. 2007). Such high temporal sampling provides unprecedented opportunity to research rapidly evolving weather phenomena and explore the potential to extend warning lead-time for severe weather.

To demonstrate the rapid-scan capability of the phased array antenna, data were collected in 2006 on a variety of severe convective storms using scanning strategies with volumetric updates ranging from 18 to 58 s. Radar meteorologists used these data to investigate meteorological advantages of the higher temporal sampling capability of the phased array radar (PAR) compared to the WSR-88D by performing detailed comparative analysis of storm structure and evolution of a supercell (24 April 2006), merging multicells (30 May 2006), and a hail storm (15 August 2006; Heinselman et al. 2007). Additionally, Smith et al. (2006) compared sampling of a microburst from PAR data to that of both the Twin Lakes, OK WSR-88D (KTLX) and the Oklahoma City Terminal Doppler Weather Radar (10 July 2006). Together, these two studies demonstrate the capability of PAR to provide the high-temporal resolution data needed for early detection of significant storm development, hail signatures, gust fronts, wind shear, and microburst precursors and suggest that PAR data have the potential to benefit short-term forecasting and warnings.

The NWRT demonstration has four objectives: 1) to assess the benefits and challenges of rapid update volumetric PAR moments (reflectivity, velocity, and spectrum width) to data interpretation and warning decision-making, 2) to emulate adaptable scanning, 3) attain data sets for several research projects, and 4) to obtain high temporal and spatial resolution severe storm verification to support PAR application development and data analysis. In this paper, a description of each of the five experiments supporting these objectives follows an overview of the scope of the NWRT demonstration. Additional information about the NWRT demonstration is available at: http://www.nssl.noaa.gov/projects/pardemo/.

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2. SCOPE

The NWRT demonstration is occurring at the National Oceanic and Atmospheric Administration (NOAA) Hazardous Weather Testbed (NHWT) located within the National Weather Center (NWC) in Norman, Oklahoma from 18 April through 15 June 2007. During this period, experienced local forecasters (e.g., from Norman WFO and the Warning Decision Training Branch) and three forecasters from Weather Forecast Offices (WFOs) across the Nation, are participating in real-time PAR data collection, interpretation, and simulated warning decision-making in coordination with NWC research meteorologists.

On days when severe convective storms are forecast within a 150-km radius of the PAR (Fig. 1), the NWRT demonstration leader, research meteorologist, and forecaster conduct PAR operations in the NHWT with guidance from the NHWT coordinator (Section 3.2). To become familiar with PAR operations and to maintain situational awareness, the team begins data collection at the onset of storm development within the NWRT domain. An online PAR training module is also available to help participants attain a basic knowledge of how the PAR works, the similarities and differences between the NWRT PAR and the WSR-88D, and the advantages and limitations of the PAR (http://www.nssl.noaa.gov/projects/pardemo). Since forecasters will participate in multiple projects at the NHWT, they are asked to contribute to PAR operations in 3 hour blocks during severe weather.

Data collection terminates at the end of warning operations or at the discretion of the team when forecast severe weather does not materialize. PAR data collection is accomplished 24 hours a day, seven days a week, as human resources permit. When long-lived events (e.g., late afternoon through early morning) are anticipated, a back-up team is recommended. The next section describes the NWRT demonstration experiments and participant responsibilities in more detail.

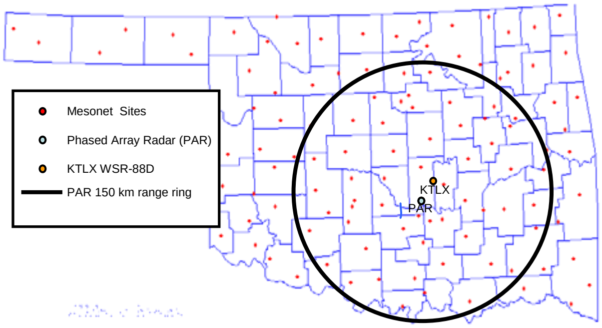


Figure 1. Maximum areal coverage (150 km) of NWRT demonstration.

3. NWRT DEMONSTRATION EXPERIMENTS

The NWRT demonstration includes the following five interrelated experiments:

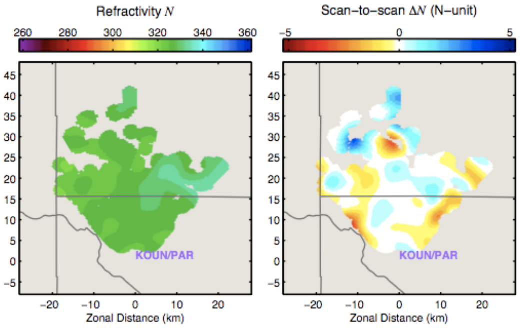
- Study of Convective Initiation and Storm Evolution Using Rapid-update Refractivity Fields From the PAR
- Real-time Simulation of Warning Decision-making Experiment
- Phased Array SMART-R Spring Experiment (PASSE),
- Data Assimilation Resolution Experiment (DARE), and
- High temporal and spatial resolution severe storm verification to support PAR application development and data analysis

3.1 Study of convective initiation and storm evolution using rapid-update refractivity fields from the PAR (Robert D. Palmer and Boon Leng Cheong)

The analysis and prediction of convective-scale weather and quantitative precipitation are known to be very sensitive to boundary layer moisture. Further, fine-scale structures in boundary layer moisture, associated with, e.g., boundary layer convective rolls, can determine the exact timing and location of convective initiation. Currently, the prediction and understanding of convection initiation processes, as well as the subsequent intensity, areal coverage, and distribution of convective rainfall, are, however, seriously hindered by inaccurate and incomplete water vapor measurements.

Recently, Doppler radars have been used to measure the near-surface refractivity field using ground target echoes (Fabry et al. 1997). These developments have been exciting to the meteorological community given that refractivity is strongly dependent on atmospheric moisture (and on temperature and pressure to a lesser degree). As a result, it is possible to use refractivity as a proxy for moisture, providing a radar-based method of estimating near-surface water vapor fields with unprecedented spatial and temporal resolutions.

During the spring 2007 storm season, the goal is to collect several cases (~ 5) of time-series data, which will be used to derive refractivity fields using the PAR. These data will be collected by specific individuals, rather than by the forecaster/researcher team, prior to expected convection in order to study the initiation process. During the pre-storm period (~2 h), data will be collected with a 360-degree coverage in order to provide more opportunity of observing the environment of a wider variety of storms (see Appendix A for Refractivity Volume Coverage Pattern (VCP)). After storm initiation, the mode will be switched to a single 90° sector using a pre-determined coverage pattern. At this point, the radar operator may be joined by the forecaster or a new forecaster/researcher team may take over operations. Regardless, these data will also be analyzed to produce refractivity fields for the study of storm evolution. Example refractivity (absolute and scan-to-scan change) fields, measured using the PAR, are provided in the figure below (Cheong et al. 2007).



3.2 Real-time Simulation of Warning Decision-making Experiment (Pam Heinselman, David Priegnitz, and Dave Andra)

The goals of the Real-time Simulation of Warning Decision-making Experiment are to

1. introduce real-time PAR data to operational forecasters,
2. attain information from forecasters and researchers about the benefits and challenges of interpreting PAR data and

making simulated warning decisions (forecasters only),

3. and to emulate adaptable scanning and attain feedback on this capability (Priegnitz et al. 2007).

Goals two and three will be met by accumulating responses to a survey designed to measure the impact of rapid scanning on PAR data interpretation and simulated warnings (Appendix B). Additionally, the survey is developed to measure the benefits and challenges of adaptable scanning.

In the real-time simulation, the forecaster interprets the PAR and makes simulated warning decisions as appropriate, while the lead/researcher team runs the PAR data collection and maintains situational awareness. A more detailed description of duties assigned to the forecaster, lead/ researcher, and NHWT coordinator (person overseeing all experiments) follows.

On days when severe weather warning operations are anticipated, the day's activities unfold as follows. The NHWT coordinator (person over-seeing all experiments in the NHWT) determines the weather focus of the day (storm type(s), location, timing, etc.) and provides a briefing by noon CDT. The coordinator for the NHWT also make decisions about data collection priorities and assists with synchronization of related field experiments (e.g., PASSE or DARE experiment, described in section 3.3 and 3.4, respectively).

Prior to operations, the lead ensures that the PAR is on generator power, the PAR antenna is operable, and that data are displayable on the Warning Decision Support System – Integrated Information (WDSS-II; Lakshmanan et al. 2007). The NWRT on-duty team will use the NHWT coordinator's briefing and data collection prioritization plan to determine their data collection strategy: starting time, duration, VCP to use, and the relative need for a back-up team. Note that, unlike conventional radars (e.g., WSR-88D), PAR has the capability of adaptable scanning. Two key aspects of adaptive scanning are the ability to optimally scan a weather echo based on storm type, size, and distance from the radar and to implement the best scanning strategies as the storm evolves (Priegnitz et al. 2007). Dwelling on specific severe weather phenomena will support both the real time evaluation of rapid-update data and post-data analysis. The VCPs currently implemented for data collection are shown in Appendix A).

Once data collection begins, the responsibilities of the forecaster are to:

- Assist lead and research meteorologist in the choice of scanning angle, sector size, and VCP to collect data on the evolution of rapidly evolving severe weather phenomena like hail, straight-line winds, microbursts, and tornadoes.
- Interrogate and interpret phased array radar base data and/or derived products using the WDSSII display.
- Issue simulated warning decisions using WDSSII, and
- Assess the benefits and challenges of adaptive scanning and PAR data to data interpretation and warning decisions by responding to a during-shift questionnaire (Appendix B).

In the same period, the responsibilities of the lead and researcher are to:

- Run the data collection via the Radar Control Interface (RCI; Priegnitz and Forsyth 2007),
- Assist forecaster in the choice of scanning angle, sector size, and VCP to collect data on the evolution of rapidly evolving severe weather phenomena like hail, straight-line winds, microbursts, and tornadoes.
- Interrogate and interpret phased array radar base data and/or derived products using the WDSSII display.
- Assess the benefits and challenges of adaptive scanning and PAR data to data interpretation by responding to a during-shift questionnaire (Appendix B).

An early test of the PAR in the NHWT came during the evening of 8 May 2007 when a mesoscale convective vortex (MCV) generated by upstream convection tracked across southwest and central Oklahoma. Locally enhanced shear along the north and east flanks of the MCV was sufficient to support several supercell thunderstorms between about 00 UTC and 06 UTC (9 May 2007 UTC). The storm structures sampled by regional WSR-88D radars and the PAR ranged from classic supercells to mini-supercells, with mini-supercells observed exclusively in the later portion of the event as the MCV tracked into central Oklahoma.

Figure 2 depicts storm relative velocity data for both MPAR and the nearby Twin Lakes WSR-88D (KTLX) radar between 04:21 and 04:29 UTC. The MPAR collected 0.5° elevation scans approximately every 30 s while the KTLX radar sampled approximately every 4 min. In this example several small cyclonic shear signatures (radars to lower right) are evident. One of these signatures, marked by a circle, was associated with a weak short-lived tornado about 49 km from the PAR and 63.9 km from the KTLX WSR-88D. A detailed damage assessment was performed to document the tornado track, which was spatially consistent with the Tornadic Vortex Signature. The PAR scans offer the advantage of improved temporal resolution which helps improve confidence about evolution of the hazard, its location, and the intensity of the signature (i.e. more samples make it more likely peak values will be sampled).

3.3 Phased array SMART-R Spring Experiment Lou Wicker, Don Burgess, Mike Biggerstaff, David Dowell)

The Phased array SMART-R Spring Experiment (PASSE) is a small field program, centered in central and western Oklahoma, which closely coordinates data collection activities with the PAR. This experiment will run from about 1 May–7 June 2007 and focus on supercell storms within 100 km of the PAR. When the SMART radar team is in the field and supercell storms are within 0–90 km of the PAR, either PASSE51 (second trip echo absent) or PASSE52 (second trip echo possible) VCP will be run continuously for a period of ~45 min (Appendix A). For supercell storms, it is believed that assimilation of the lowest few kilometers of the atmosphere is critical. Hence, PASSE focuses on data collection at low altitudes.

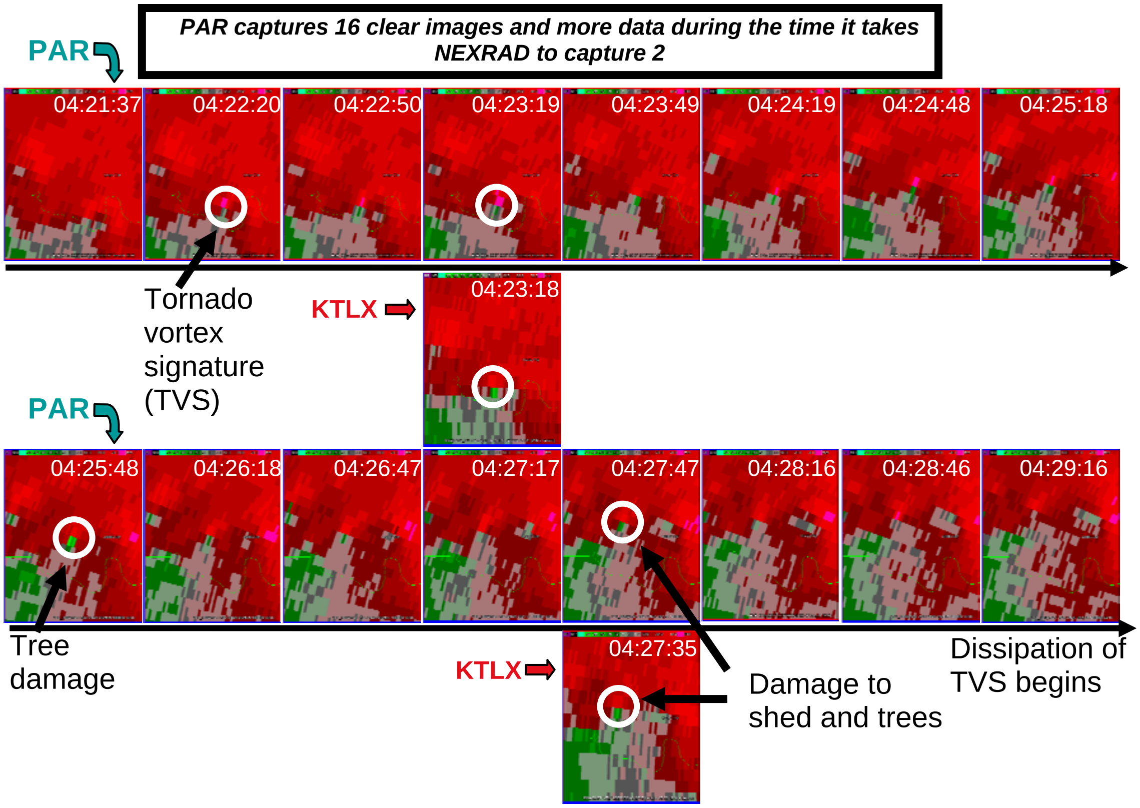

PAR captures 16 clear images and more data during the time it takes NEXRAD to capture 2

Figure 2. Time sequence of 0.5° elevation velocity data collected by the phased array radar (PAR, top rows) and the Twin Lakes WSR-88D (KTLX, bottom rows) between 042139 UTC and 042916 UTC on 9 May 2007. Both radars are located to the lower right (east-southeast) of the images. At ~042318 UTC, the tornado vortex signature is located 49 km from PAR and 63.9 km from KTLX. Note that the PAR's rapid sampling depicts the tornado vortex signature (TVS) approximately one minute before the WSR-88D and provides a more full depiction of the TVS's evolution.

The SMART radars will be positioned such that targets of interest will be in dual-Doppler lobes between the PAR and SMART-R's (Fig. 3), thereby facilitating three-dimensional wind synthesis and eventually validation of the data assimilation results using the cross-beam wind information and reflectivity measurements. Typically one of the SMART radars will be located near the PAR. However, a "stacked" deployment strategy at either L1 or L2 (Fig. 3) may also be used to mimic, as much as possible, the data stream that the PAR system generates.

This project has three major goals that involve both radar and modeling research:

1. Post-process and then compare in some detail the differences in radar parameters between systems for at least one specific case examining the differences in reflectivity and radial velocity structure between the conventional radar and the PAR as a function of time and space.

2. **2.** Evaluate the impact of rapid updates on storm scale forecasts at varying temporal resolutions by assimilating PAR data using the NSSL Ensemble Kalman Filter system (PyEnCOMMAS) to produce a storm-scale analysis and forecast for one specific case.

3. **3.** Use the SMART radar data to validate the PAR-derived analyses.

3.4 Data Assimilation Resolution Experiment (DARE; *Mike Biggerstaff and Lou Wicker*)

Observations of convective storms often focus on the lowest levels where severe weather has the greatest impact. Yet it is well known that the statistical characteristics of convective cells within mesoscale cloud systems vary most at mid-to-upper levels of the atmosphere. Previous observations of multicell storms have rather low vertical resolution due to large steps in elevation angles between PPI sweeps to minimize the time required to complete a volume scan. This has resulted in an under-sampling of the vertical structure of multicell storm systems in the layer where the storm evolution is fast. The mid-to-upper levels are important for cloud electrification and up-scale growth of precipitation. Better diagnosis of this part of the storm system should improve our ability to model multicell storms for lightning research, quantitative precipitation forecasts, and hail prediction. The objective of the Data Assimilation Resolution Experiment (DARE) is to evaluate the impact of time-space resolution tradeoffs in the diagnosed structure of multicell storms, particularly the mixed phase region important for cloud electrification and mesoscale precipitation development. DARE will run concurrently with the PASSE such that on days with supercells PASSE has priority and on days with multicell storms DARE has priority.

When SMART radar project leaders are out in the field and multicell storms are occurring within 75 km of the PAR, coordinated dual-Doppler sampling between the PAR and the SMART radars in a "stacked" configuration will be used to evaluate the impact of time-space resolution on diagnosed storm structure. The two SMART-radars will be quasi-co-located with one SMART radar sampling the low-to-mid levels and the other SMART radar sampling the mid-to-upper levels (Fig. 3). The PAR operator will perform 90° sector scans with a cycle of four tasks ranging from one to four minute durations in steps of one minute (Appendix A, Tables 4–7). Repeating the 20 minute cycle three times while deep convection is in the dual-Doppler region for four different multicell events will provide adequate statistical information to evaluate the tradeoffs between increased vertical resolution or increased temporal resolution for this type of storm system.

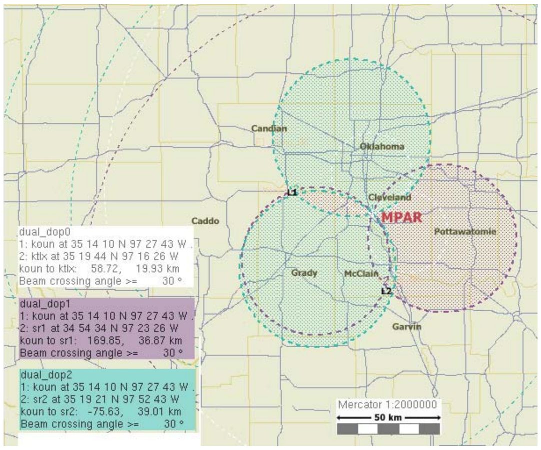


Figure 3. Study region for the coordinated PAR/stacked-SMART radar deployment. Note that the data collection will focus over only one of the lobes for any given event. Possible SMART radar sites are denoted by L1 and L2.

3.5 High temporal and spatial resolution severe storm verification to support PAR application development and data analysis

This project will thoroughly document as many severe weather events as possible that are observed with the PAR. These events include tornadoes, hail, and damaging winds from microbursts and larger scale convective systems. We will employ several effective and inexpensive techniques for data gathering, which include but are not limited to:

- Targeted post-event telephone surveys of the public using GIS tools and publicly available telephone number and address information (as conducted during the Severe Hail Verification Experiment in 2006);
- Post-event damage surveys using the EFKit software (for EF-scale damage rating), GPS logging, and geo-referenced photography;
- interfacing with spotternetwork.org for real-time chaser/spotter reports; and
- post-event "web clippings" from news services to collect photography and video of events and damage.

This experiment will provide high-density verification information for the PAR that will support the development of scientifically sound severe storm guidance applications and techniques.

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Appendix A

Table 1. "Refractivity on the NWRT" VCP, scanning strategy #1. This VCP will be run during the 2-hour period prior to expected convection.

Sector	Elev	PRT1	Pulses1	Nyquist	Rmax1	Time (seconds)
1st 90°	0.51	800	64	29.30	119.9	18.432
2nd 90°	0.51	800	64	29.30	119.9	18.432
3rd 90°	0.51	800	64	29.30	119.9	18.432
4th 90°	0.51	800	64	29.30	119.9	18.432
Time to complete 360° scan						**73.728**

Table 2. PASSE51 VCP. This VCP will be run when supercells exist within 10–90 km of PAR and second trip contamination is absent. This VCP is run in continuous doppler mode (CDM) and takes ~30 s to complete when run over a 90° sector.

Elev	PRT1 (μs)	Pulses1	PRT2 (μs)	Pulses2	Nyquist1 (m s^{-1})	Nyquist2 (m s^{-1})	Rmax1 (km)	Rmax2 (km)	Time (seconds)
0.51	800	52	NA	16	29.3	NA	120	NA	0.0416
0.9	800	52		16	29.3		120		0.0416
1.3	800	52		16	29.3		120		0.0416
2.1	800	52		16	29.3		120		0.0416
2.9	800	52		16	29.3		120		0.0416
3.8	800	52		16	29.3		120		0.0416
4.7	800	52		16	29.3		120		0.0416
5.6	800	52		16	29.3		120		0.0416
Time to complete one vertical slice									**0.3328**

Table 3. PASSE52 VCP. This VCP will be run when supercells exist within 10–90 km of PAR and second trip contamination is possible. This VCP is run in batch mode (BM) and takes ~30 s to complete (90° sector).

Elev	PRT1 (μs)	Pulses1	PRT2 (μs)	Pulses2	Nyquist1 (m s^{-1})	Nyquist2 (m s^{-1})	Rmax1 (km)	Rmax2 (km)	Time (seconds)
0.51	1000	16	1500	16	23.5	15.6	150	225	0.04
0.9	1000	16	1500	16	23.5	15.6	150	225	0.04
1.3	1000	16	1500	16	23.5	15.6	150	225	0.04
2.1	1000	16	1500	16	23.5	15.6	150	225	0.04
2.9	1000	16	1500	16	23.5	15.6	150	225	0.04
3.8	1000	16	1500	16	23.5	15.6	150	225	0.04
4.7	1000	16	1500	16	23.5	15.6	150	225	0.04
5.6	1000	16	1500	16	23.5	15.6	150	225	0.04
Time to complete one vertical slice									**0.32**

Table 4. DARE61 VCP. This VCP has 11 tilts and will be run when multicells exist within 75 km of the PAR. This VCP is contains both BM and CDM (7° and higher) and takes ~60 s to complete (90° sector). It is the first of four DARE VCPs that will be run during this experiment. Number of repetitions is three and waiting time between scans is 15 s.

Elev	PRT1 (μs)	Pulses1	PRT2 (μs)	Pulses2	Nyquist1 (m s^{-1})	Nyquist2 (m s^{-1})	Rmax1 (km)	Rmax2 (km)	Time (seconds)
1	1667	16	833	64	14.1	28	250	125	0.08
3	1667	16	833	64	14.1	28	250	125	0.08
5	1667	16	833	64	14.1	28	250	125	0.08
7			833	64		28		125	0.0533
9			833	64		28		125	0.0533
12			800	64		28		120	0.0512
15			800	64		28		120	0.0512
18			800	64		28		120	0.0512
21			800	64		28		120	0.0512
25			800	64		28		120	0.0512
30			800	64		28		120	0.0512
Time to complete one vertical slice									**0.6538**

Table 5. DARE62 VCP. This VCP contains 21 tilts and will be run when multicells exist within 75 km of the PAR. This VCP is contains both BM and CDM (6° and higher) and takes ~110 s (1.83 min) to complete (90° sector). It is the second of four DARE VCPs that will be run during this experiment. Number of repetitions is two and waiting time between scans is 20 s.

Elev	PRT1 (μs)	Pulses1	PRT2 (μs)	Pulses2	Nyquist1 (m s^{-1})	Nyquist2 (m s^{-1})	Rmax1 (km)	Rmax2 (km)	Time (seconds)
1	1667	16	833	64	14.1	28	250	125	0.08
2	1667	16	833	64	14.1	28	250	125	0.08
3	1667	16	833	64	14.1	28	250	125	0.08
4	1667	16	833	64	14.1	28	250	125	0.08
5	1667	16	833	64	14.1	28	250	125	0.08
6			833	64		28		125	0.0533
7			833	64		28		125	0.0533
8			833	64		28		125	0.0533
9			833	64		28		125	0.0533
10.5			800	64		28		120	0.0512
12			800	64		28		120	0.0512
13.5			800	64		28		120	0.0512
15			800	64		28		120	0.0512
16.5			800	64		28		120	0.0512
18			800	64		28		120	0.0512
19.5			800	64		28		120	0.0512
21			800	64		28		120	0.0512
23			800	64		28		120	0.0512
25			800	64		28		120	0.0512
27.5			800	64		28		120	0.0512
30			800	64		28		120	0.0512

Time to complete one vertical slice	**1.2276**

Table 6. DARE63 VCP. This VCP contains 33 tilts and will be run when multicells exist within 75 km of the PAR. This VCP is contains both BM and CDM (5.7° and higher) and takes ~177 s (2.95 min) to complete (90° sector). It is the third of four DARE VCPs that will be run during this experiment. Number of repetitions is two and waiting time between scans is 23 s.

Elev	PRT1 (μs)	Pulses1	PRT2 (μs)	Pulses2	Nyquist1 (m s^{-1})	Nyquist2 (m s^{-1})	Rmax1 (km)	Rmax2 (km)	Time (seconds)
0.51	1667	16	833	64	14.1	28	250	125	0.08
1	1667	16	833	64	14.1	28	250	125	0.08
1.5	1667	16	833	64	14.1	28	250	125	0.08
2	1667	16	833	64	14.1	28	250	125	0.08
2.5	1667	16	833	64	14.1	28	250	125	0.08
3	1667	16	833	64	14.1	28	250	125	0.08
3.7	1667	16	833	64	14.1	28	250	125	0.08
4.4	1667	16	833	64	14.1	28	250	125	0.08
5.	1667	16	833	64	14.1	28	250	125	0.08
5.7			833	64		28		125	0.0533
6.3			833	64		28		125	0.0533
7			833	64		28		125	0.0533
7.7			833	64		28		125	0.0533
8.3			833	64		28		125	0.0533
9			833	64		28		125	0.0533
10			800	64		28		120	0.0512
11			800	64		28		120	0.0512
12			800	64		28		120	0.0512
13			800	64		28		120	0.0512
14			800	64		28		120	0.0512
15			800	64		28		120	0.0512
16			800	64		28		120	0.0512
17			800	64		28		120	0.0512
18			800	64		28		120	0.0512
19			800	64		28		120	0.0512
20			800	64		28		120	0.0512
21			800	64		28		120	0.0512
22.3			800	64		28		120	0.0512
23.7			800	64		28		120	0.0512
25			800	64		28		120	0.0512
26.7			800	64		28		120	0.0512
28.3			800	64		28		120	0.0512
30			800	64		28		120	0.0512
Time to complete one vertical slice									**1.2276**

Table 7. DARE64 VCP. This VCP contains 42 tilts and will be run when multicells exist within 75 km of the PAR. This VCP is contains both BM and CDM (5.5° and higher) and takes ~235 s (3.91 min) to complete (90° sector). It is the second of four DARE VCPs that will be run during this experiment. Number of repetitions is two and waiting time between scans is 30 s.

Elev	PRT1 (μs)	Pulses1	PRT2 (μs)	Pulses2	Nyquist1 (m s^{-1})	Nyquist2 (m s^{-1})	Rmax1 (km)	Rmax2 (km)	Time (seconds)
0.51	1667	16	833	64	14.1	28	250	125	0.08
0.7	1667	16	833	64	14.1	28	250	125	0.08
1	1667	16	833	64	14.1	28	250	125	0.08
1.3	1667	16	833	64	14.1	28	250	125	0.08
1.5	1667	16	833	64	14.1	28	250	125	0.08
2	1667	16	833	64	14.1	28	250	125	0.08
2.5	1667	16	833	64	14.1	28	250	125	0.08
3	1667	16	833	64	14.1	28	250	125	0.08
3.5	1667	16	833	64	14.1	28	250	125	0.08
4	1667	16	833	64	14.1	28	250	125	0.08
4.5	1667	16	833	64	14.1	28	250	125	0.08
5	1667	16	833	64	14.1	28	250	125	0.08
5.5			833	64		28		125	0.0533
6.			833	64		28		125	0.0533
6.5			833	64		28		125	0.0533
7			833	64		28		125	0.0533
7.5			833	64		28		125	0.0533
8.			833	64		28		125	0.0533
8.5			833	64		28		125	0.0533
9			833	64		28		125	0.0533
9.8			833	64		28		125	0.0533
10.5			800	64		28		120	0.0512
11.3			800	64		28		120	0.0512
12			800	64		28		120	0.0512
13.5			800	64		28		120	0.0512
14.3			800	64		28		120	0.0512
15			800	64		28		120	0.0512
15.8			800	64		28		120	0.0512
16.5			800	64		28		120	0.0512
17.3			800	64		28		120	0.0512
18			800	64		28		120	0.0512
18.8			800	64		28		120	0.0512
19.5			800	64		28		120	0.0512
20.3			800	64		28		120	0.0512
21			800	64		28		120	0.0512
22			800	64		28		120	0.0512
23			800	64		28		120	0.0512
24			800	64		28		120	0.0512
25			800	64		28		120	0.0512
26.3			800	64		28		120	0.0512
27.5			800	64		28		120	0.0512
28.8			800	64		28		120	0.0512
30			800	64		28		120	0.0512

Time to complete one vertical slice	**1.2276**

Table 8. VCP12 . This VCP is the PAR equivalent of the NWS VCP12 scanning strategy. It will be used in general situations for comparison with KTLX.

Elev	PRT1 (μs)	Pulses1	PRT2 (μs)	Pulses2	Nyquist1 (m s^{-1})	Nyquist2 (m s^{-1})	Rmax1 (km)	Rmax2 (km)	Time (seconds)
0.51	3107	15					465		0.047
0.51			898	44		26.1		135	0.040
0.9	3107	15					465		0.047
0.9			898	44		26.1		135	0.040
1.3	3107	15					465		0.047
1.3			898	44		26.1		135	0.040
1.8	3107	3	898	32		26.1	465	135	0.038
2.4	2240	3	898	33		26.1	336	135	0.036
3.1	2240	3	898	33		26.1	336	135	0.036
4.0	2240	3	898	33		26.1	336	135	0.036
5.1	1553	3	898	33		26.1	233	135	0.034
6.4	1553	3	898	33		26.1	233	135	0.034
8.0			831	42		28.2		125	0.035
10.0			800	43		29.3		120	0.034
12.5			800	43		29.3		120	0.034
15.6			800	43		29.3		120	0.034
19.5			800	43		29.3		120	0.034
Time to complete one vertical slice									**0.647**

Table 9. Enhanced VCP12 . This VCP is the PAR equivalent of the NWS VCP12 scanning strategy with additional higher elevation cuts added to better capture the top portions of “close” storms.

Elev	PRT1 (μs)	Pulses1	PRT2 (μs)	Pulses2	Nyquist1 (m s^{-1})	Nyquist2 (m s^{-1})	Rmax1 (km)	Rmax2 (km)	Time (seconds)
0.51	3107	15					465		0.047
0.51			898	44		26.1		135	0.040
0.9	3107	15					465		0.047
0.9			898	44		26.1		135	0.040
1.3	3107	15					465		0.047
1.3			898	44		26.1		135	0.040
1.8	3107	3	898	32		26.1	465	135	0.038
2.4	2240	3	898	33		26.1	336	135	0.036
3.1	2240	3	898	33		26.1	336	135	0.036
4.0	2240	3	898	33		26.1	336	135	0.036
5.1	1553	3	898	33		26.1	233	135	0.034
6.5	1553	3	898	33		26.1	233	135	0.034
8.0			831	42		28.2		125	0.035
10.0			800	43		29.3		120	0.034
12.0			800	43		29.3		120	0.034
14.0			800	43		29.3		120	0.034
16.0			800	43		29.3		120	0.034
18.0			800	43		29.3		120	0.034
20.0			800	43		29.3		120	0.034
22.0			800	43		29.3		120	0.034
24.0			800	43		29.3		120	0.034
26.0			800	43		29.3		120	0.034
28.0			800	43		29.3		120	0.034
30.0			800	43		29.3		120	0.034
Time to complete one vertical slice									**0.887**

Appendix B

Name ___________________   Date_________ Time period _____________________

Impact of Rapid Scanning on Data Interpretation

1) For each storm you examine in detail, keep a record of storm type, time period, and how increased temporal resolution was beneficial and/or challenging to your interpretation of storm structure, severity, etc. *Include any storm features you can detect more easily or that you may not have seen before.*

	Benefits to data interpretation	Challenges to data interpretation
Feature:		
Time period (UTC) _________to _________		
Feature:		
Time period (UTC) _________to____________		
Feature:		
Time period (UTC) ___________ to ____________		
Feature:		
Time period (UTC) ___________ to ____________		

2) Rate the extent to which you are seeing storm features in phased array radar data in a way that is more recognizable compared to the WSR-88D.

None Some High
① ② ③ ④ ⑤ ⑥ ⑦

3) Rate the suitability of the following visual presentation type(s) to your phased array radar data interpretation and decision-making.

PPI	Low ① ② ③ ④ ⑤ ⑥ ⑦ High
CAPPI	Low ① ② ③ ④ ⑤ ⑥ ⑦ High
Vertical cross section	Low ① ② ③ ④ ⑤ ⑥ ⑦ High
3-D Visualization	Low ① ② ③ ④ ⑤ ⑥ ⑦ High
Animation	Low ① ② ③ ④ ⑤ ⑥ ⑦ High

What other visualization tools would have been helpful?

4) Rate the overall benefit of rapid scan radar data to the detection and evolution of significant weather.

None Some High
① ② ③ ④ ⑤ ⑥ ⑦

Scanning Strategy Choices

5) The following questions pertain to scanning strategy choices.

a) If you had the opportunity to design your own scanning strategies, is there something that you would do differently?

b) What information did you use to make scanning decisions (e.g., radar range, storm type, storm height, etc.)?

c) Rate the difficulty of the process for choosing sector size and VCPs. *Explain the rating.*

None Some High
① ② ③ ④ ⑤ ⑥ ⑦

Explanation:

d) Rate the benefit of being able to modify sector size and VCPs in real time to data interpretation and decision-making. *Explain the rating.*

None Some High
① ② ③ ④ ⑤ ⑥ ⑦

Explanation:

e) Rate the user-friendliness of the radar control interface and comment on desired improvements.

None Some High
① ② ③ ④ ⑤ ⑥ ⑦

Desired improvements:

Warning Decision-making

6) The following questions pertain to warning decision-making.

a) Rate the impact of rapid-scan phased array radar data on your warning decision-making. *Explain the rating.*

Negative None High
① ② ③ ④ ⑤ ⑥ ⑦

Explanation:

b) To what extent did data quality impede interpretation of storm signatures?

None Some High
① ② ③ ④ ⑤ ⑥ ⑦

Overall Impression

7) What was your overall impression on the usefulness of phased array radar technology in the forecasting of severe weather phenomena *(with the understanding that the NWRT is a research radar with limited capability relative to a complete, higher resolution phased array radar)*?

Benefits:	Challenges: