P155 Multifunction Phased Array Radar Wind Shear Experiment

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1. INTRODUCTION

Terminal Doppler Weather Radars (TDWRs) provide near-ground wind shear detection that is critical for aircraft safety at 46 airports across the United States. These systems are part of the larger network of 510 weather and aircraft surveillance radars owned and operated by government agencies in the continental United States. As the TDWR and other radar systems approach their engineering design life cycles, the Federal Aviation Administration (FAA), National Weather Service (NWS), and Department of Defense (DoD) are considering potential replacement systems (OFCM 2006; Weber et al. 2007).

One option under consideration that would maintain the current airspace coverage is a replacement network of 334 Multifunction Phased Array Radars (MPARs) (Weber et al. 2007). The MPAR network described by Weber et al. (2007) would include two classes of systems: A high-resolution, full-scale version with an 8-m diameter antenna, and a lower-resolution terminal version with a 4-m diameter antenna, termed Terminal MPAR, or TMPAR. As the proposed TMPAR design has lower azimuthal beam resolution and less sensitivity than TDWRs, it is crucial to determine the impacts of that design on the detection of low-altitude wind shear.

The design of the SPY-1A PAR, a research radar at the National Weather Radar Test Bed in Norman, Oklahoma (Zrnić et al. 2007), makes it a good proxy for examining the potential wind shear detection performance of the TMPAR. Therefore, in spring 2012, the National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory organized and executed the MPAR Wind Shear Experiment (WSE) in collaboration with the FAA, NOAA's NWS Radar Operations Center, the University of Oklahoma Advanced Radar Research Center (OU ARRC), and the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL). The primary objective of the MPAR WSE was to collect low-altitude observations with the SPY-1A PAR (hereafter, PAR) for comparison with observations from the nearby Oklahoma City (OKC) TDWR. Of particular interest is comparison of MIT LL wind shear detection algorithm performance using data from these two radars; this analysis is reported in Cho et al. (2013). Data were also collected from other radars in central Oklahoma to facilitate basic research on microbursts and other wind-producing storms.

This paper provides an overview of the MPAR WSE and observed wind shear events.

2. RADARS

During the MPAR WSE, data were collected from a set of operational and research radars located in central Oklahoma (Table 1). Given the interest in low-altitude wind shear detection, data collection focused on storms observed within 60 km of the OKC TDWR. For microburst detection, the lowest elevation scan is most critical because the potentially damaging winds and associated wind shift occur near the surface.

Research radars run during the experiment included the dual-polarization KOUN and KCRI WSR-88D test bed radars, and the X-band PX-1000 (Cheong et al. 2012). The PX-1000, which stands for Polarimetric, X-band, 08 (1000 in binary, the year the idea was conceived), is a trailer-mounted, dual-polarization X-band radar of the Advanced Radar Research Center (ARRC).

Both the TDWR and PAR provided rapid updates (~1 min) of the lowest elevation scan, which is desirable due to the relatively short lifetime of microbursts (e.g., Wilson et al. 1984). Unique to the PAR was the denser and more rapid vertical sampling of mid-to-upper altitude radar-based precursors (e.g., Roberts and Wilson 1989) necessary for microburst prediction (Heinselman et al. 2008). Dual-polarization variables observed by KOUN and PX-1000 will aid investigation of the microphysical processes involved in the development of intense downdrafts (e.g., Srivastava 1987; Proctor 1989). Descriptions of the radars used during the experiment and their respective scan strategies follows.

2.1 OKC TDWR

The OKC TDWR is a C-band Doppler radar with fine range resolution and azimuthal sample spacing, and sensitivity similar to a WSR-88D (Table 1). Operational TDWRs use two volume scan strategies—monitor and hazard (Istok et al. 2009). The monitor scan is the default used when no hazardous weather is detected. It scans from the surface up to 60° elevation and repeats every ~5 minutes. When hazardous weather is detected, the scan strategy is automatically switched to hazard mode. In this mode the maximum elevation angle is

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Table 1. Operating characteristics of the five radar systems. *Transmit beam width.

	TDWR	PAR	KOUN / KCRI / KTLX	PX-1000
Operating band	C-band	S-band	S-band	X-band
Antenna altitude	385 m	369.7 m	394.4 / 400.5 / 389.2 m	394.4 m
Max elevation angle	60°	~90°	19°	90°
Min observation range	0.5 km	3.0 km	1 km	0.5 km
Range resolution	0.15 km	0.24	0.25, 1 km	0.18 km
Beam width	0.55°	*1.5– 2.1°	0.925	1.8°
Azimuthal sampling	1°	0.75, 1.1°	0.5, 1°	1°
Azimuth sector scan?	No	Yes: ≤ 90°	No	Yes, but not implemented
Min. detectable dBZ at 35 km	-14	2	-13	19

~27° (max number of elevations = 9) and the lowest elevation scan is revisited every minute.

2.2 KTLX WSR-88D

The KTLX WSR-88D (Crum and Alberty 1993) is an S-band Doppler radar with slightly less fine range and azimuthal resolution than the OKC TDWR but with similar sensitivity (Table 1). Operational WSR-88Ds have nine volume coverage patterns (VCPs) available (OFCM 2011). The best VCPs for the MPAR WSE were those with the shortest update period (~4 min), i.e., VCP12 (Brown et al. 2005) and VCP212 (Zittel et al. 2008). VCP212 differs from VCP12 in that it employs better range dealiasing methods to increase effective range and to protect near-range areas from contamination by distant storms. Turning on the AVSET (automated volume scan evaluation and termination) function can decrease the volume scan time further by truncating the scan at the maximum elevation at which weather is observed (Chrisman 2009).

2.3 PAR

The PAR is an S-band vertically polarized Doppler radar with range resolution similar to the WSR-88D and azimuthal resolution ranging from 1.5 to 2 times that of the TDWR and WSR-88D. Clear-air is generally unobserved owing to the NWRT PAR's relative lack of sensitivity compared to the TDWR and WSR-88D (Table 1). We expect that these PAR attributes will result in fewer observations of reflectivity fine lines and, in some cases, lower velocity magnitudes along outflow boundaries, compared to the two operational systems.

The two volume scan strategies designed for this study were named 1) EnhancedVCP12_CLEAN_AP and 2) EnhancedVCP12_CLEAN_AP_uniform. CLEAN_AP is the ground clutter mitigation scheme applied during real-time data (Warde and Torres 2010). Range oversampling was also implemented to improve data quality and reduce scan time (Curtis and Torres 2011). Both scan strategies used 50% azimuthal oversampling at all elevations and had a Nyquist velocity of about 29.2 m s^{-1}.

The EnhancedVCP12_CLEAN_AP scans 18 elevations from 0.51° to 52.9°, employs split-cut sampling through 6.4°, and has a minimum observation range of 10 km. The scan time is 64 s. This scan strategy was used when storms existed outside of the maximum unambiguous range (117 km) to mitigate second trip returns. The uniform-PRT version of the scan strategy was developed to decrease the minimum observation range from 10 to 3 km and the scan time from 64 to 46s. Three elevations were added aloft: 60, 70 and 90°, to decrease the impact of the cone of silence on reflectivity measurements. Unfortunately, this 46-s scan strategy was not executed, as storms were wide spread and existed outside of the maximum range (~117 km) during the experiment. To minimize update time, the PAR ran the adaptive digital signal processing algorithm for PAR timely scans (ADAPTS; Heinselman and Torres 2011).

2.4 KOUN and KCRI Dual-Polarization Test Bed WSR-88Ds

KOUN and KCRI are simultaneous transmission, dual-polarization test bed WSR-88Ds with operating characteristics similar to KTLX (Table 1). See Zrnić and Ryzhkov (1999) for a detailed overview of dual-polarization variables and examples of weather applications.

In addition to the operational VCPs (OFCM 2011), a non-adaptive version of SAILS (Supplemental Adaptive Intra-Volume Low-Level Scan) called SNAILS was run on KOUN. The SNAILS inserts an extra lowest elevation (0.5°) scan between 1.8 and 2°. This strategy is closer to the TDWR Hazard mode than any other WSR-88D VCP, and is better suited for microburst detection. To minimize both the lowest elevation and volumetric update times, SNAILS with AVSET (Chrisman 2009) were run on KOUN and KCRI.

2.5 PX-1000

One of the unique features of the PX-1000 is the two identical but independent transmit-receive chains, which include two 100-W solid-state power amplifiers and waveform generators. The system uses a 1.2-m parabolic reflector dish, which provides a 1.8° 3-dB beam width and 38.5-dBi antenna gain. Major components are housed on an azimuth-over-elevation pedestal, which can perform continuous rotation. A long transmit pulse is utilized to compensate for the relatively low-peak power of the transmitters, while a pulse-compression technique is used to recover the range resolution and sensitivity.

In the MPAR WSE campaign, a time-frequency multiplexed waveform was used to fill in the blind zone, which typically exists in pulse compression radars but was mitigated with the PX-1000. The radar was set near the NWRT PAR with a wireless network connection for real-time control, monitoring and Level-II data feed. During operations, a 10-tilt volume scanning pattern (1, 3, 5, 7, 9, 11, 13, 15, 17, and 19°) was used, which provides a temporal resolution of approximately 3.5 min. A more detailed system description of the PX-1000 radar can be found in Cheong et al. (2012).

3. DATA COLLECTION AND EXAMPLE EVENT

The MPAR WSE ran from 16 April through 30 June 2012. Within most of this period, daily microburst forecasts were provided by Don Burgess (with the Cooperative Institute for Mesoscale Meteorology) to assist decisions regarding scheduling of Test Bed radar operations. Each week two scientists were scheduled to operate the PAR, 24 hours a day, 7 days a week. Collaborators were informed at the onset and end of PAR operations via e-mail. During the experiment, the PAR sampled 11 events that triggered algorithm-based wind shear detections within 60-km range of the OKC TDWR (Table 2). This data set includes one wind shear event the PAR sampled about one week before the official experiment start date.

Table 2. Dates and periods containing azimuthal wind shear signatures within 60 km of the OKC TDWR. Severe wind gusts occurred during shaded events.

Date (2012)	Period (UTC)
8 April	1356–1408
1 May	0415–0528
4 May	1342–1409
20 May	**0425–0640**
21 May	1247–1337
28 May	2230–2319
29 May	0008–0308
30 May	**0021–0320**
31 May	**0050–0550**
5 June	2103–2315
15 June	0644–0925

Though most events (8 of 11) produced relatively weak wind shear signatures, three events in May were associated with severe wind reports (dates shaded in Table 2). On 20 May, for example, as a line segment moved over Minco, Oklahoma, a Mesonet site measured 28 m s^{-1} (62.6-mph) and 29 m s^{-1} (65.5-mph) wind gusts at 0525 and 0530 UTC, respectively. About 30 min later, as the segment moved over Will Rogers Int. Airport, in Oklahoma City, the co-located ASOS (Automated Surface Observation Station) site measured a 31.3 m s^{-1} (70 mph) wind gust.

On 30 May, the multicell storm complex that formed that afternoon produced damaging wind and hail in the Oklahoma City Metro area. Total damages of $400 to $500 million were estimated (Storm Data found at http://www.srh.noaa.gov/media/oun/stormdata/oun201205.pdf). At 0140 UTC the storm complex produced winds near 26.8 m s^{-1} (60 mph) in Edmond, Oklahoma, where 10 power poles were blown down. Hail reports in Edmond and nearby Nichols Hills ranged from 1.25 to 2.75 inches; the media estimated that 8,000 to 10,000 vehicles and numerous homes were damaged. Later, at 0300 UTC, the Minco Mesonet site measured a 32 m s^{-1} (71 mph) wind gust; 2 min later the ASOS site at Will Rogers Int. Airport measured a 34 m s^{-1} (76 mph) wind gust. Each wind gust was associated with a well-defined divergence signature in the both the PAR and OKC TDWR data (Fig. 1). Within the next hour this storm also produced high winds and tree damage in Norman and Purcell.

The next evening, another round of deep convection produced strong winds, with measured wind gusts ranging from 26–29 m s^{-1} (59–61 mph) within the domain. Unlike the previous evening, no wind damage or hail were reported.

5. SUMMARY AND FUTURE WORK

During the MPAR WSE, a diverse set of radars in central Oklahoma collected data on several weak to strong microburst-producing events. The most significant wind-producing events occurred on 20, 30, and 31 May 2012. The 30 May event was the most significant in terms of social impacts. A comparison of the PAR and TDWR data associated with two high wind reports from this event show that the associated divergence signatures were well-sampled by both radars. Of more interest, though, are the processes that produced this and other significant events in the data set. The dual-polarization radars employed provide the opportunity to study the microphysical processes that drove these downdrafts. They also provide the opportunity to study differences in polarimetric signatures produced by KOUN and PX-1000.

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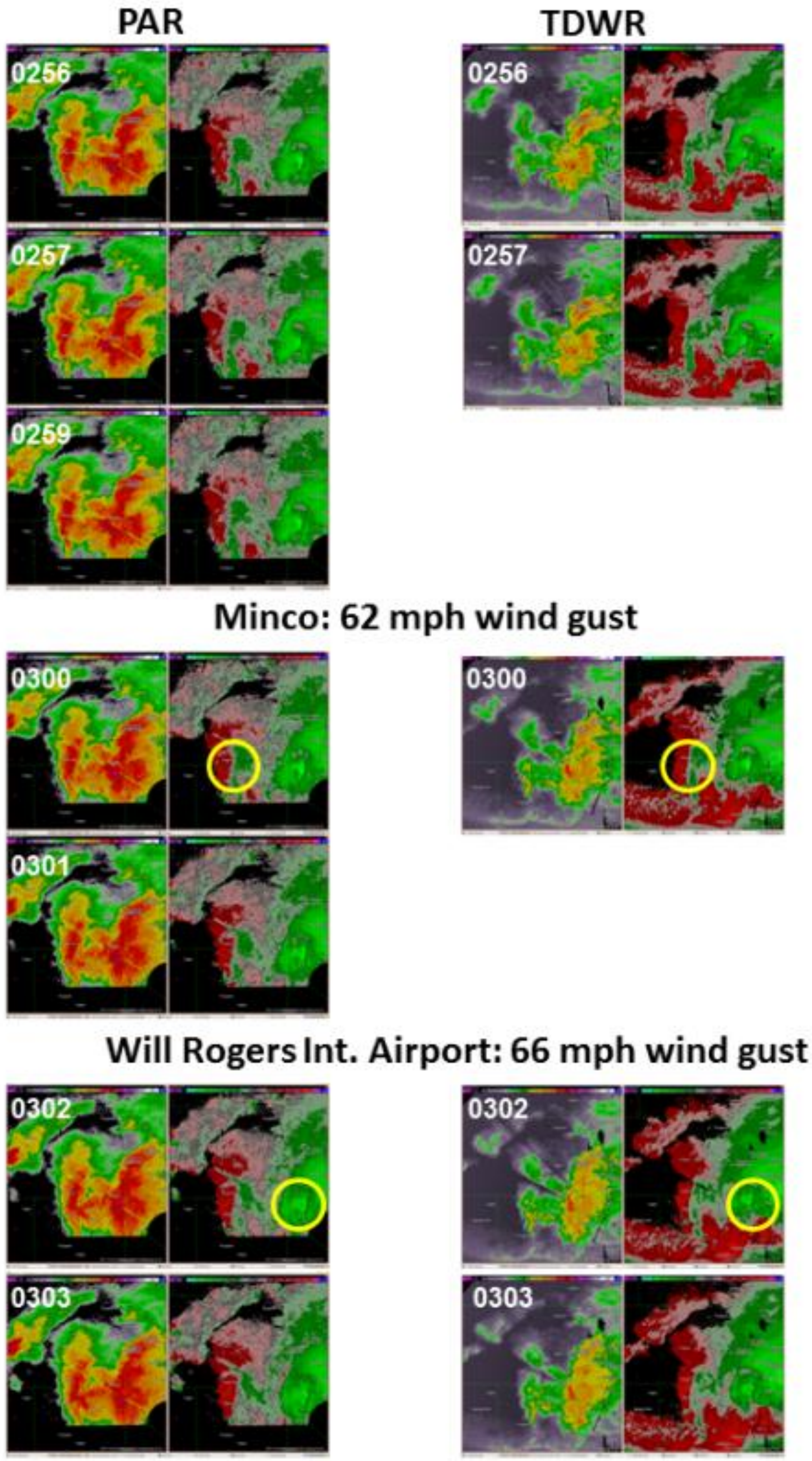

Fig. 1. Snapshots of 0.5 deg reflectivity and base velocity sampled by PAR (left column) and OKC TDWR (right column) from 0256 to 0303 UTC 30 May 2012. The yellow circles enclose the region in which a severe-criteria wind gust was measured.