First Look at Forecasters experiences with High-Temporal Resolution Phased Array Radar data: An Evaluation Research Study

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ABSTRACT

The Phased Array Radar (PAR) is a research radar that is under consideration to replace the Weather Surveillance Radar-1988 Doppler (WSR-88D). As a new technology it is important to provide user insight into the development stage to ensure intended users have the most usable tool upon deployment and not only understand the operational utility of PAR. Results from experiments held in 2008 and 2009 have already assisted researchers developing PAR. The participants of these experiments evaluated real-time and archived cases; after each evaluation questionnaires were completed. The responses to two archived cases were analyzed in this paper using a data-driven method. The results show how high-temporal resolution data of PAR impacted the participating forecasters in a simulated warning environment. Suggestions are made to improve future research and development.

1. INTRODUCTION

The Weather Surveillance Radar-1988 Doppler (WSR-88D) has been detecting detailed precipitation and wind data for much of its 20-year design lifetime. The service life has been extended via the alteration and upgrading of hardware and software for the WSR-88D (Zrnić et al. 2007). However, technological advances and the time needed to develop a replacement have led to the emergence of considerations for a replacement system or family of systems (National Academies 2008). The Phased Array Radar (PAR) is one such replacement system under consideration (Zrnić et al. 2007).

PAR originally stemmed from military employment of aircraft and missile surveillance and is now being expanded as a weather observation tool. PAR as a research radar is capable of adaptively scanning the atmosphere at high temporal resolution on the order of 1 minute or less (Heinselman et al. 2008). PAR in its prototype stage has the ability to rotate one stationary face that scans 90º sectors. Researchers can keep the face fixed to explore the impact of high temporal data on weather detection and warning. Detailed investigations of the operational utility of high temporal resolution, in regard to weather, have already been conducted (Heinselman et al. 2008). Researching the utility of PAR is just one step in determining the effectiveness of new technologies; the user feedback portion of the process ensures that the intended users of the technology provide insight into the development stage so that the end result is the most usable tool.

User involvement in the Spring 2008 Phased Array Radar experiment has positively impacted PAR research and development by helping researchers understand the most critical altitudes for high-temporal radar data

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(Heinselman 2009, personal communication). The success of that experiment led to a 2009 PAR experiment, the Phased Array Radar Innovative Sensing Experiment (PARISE). The evaluations of PAR data by participating forecasters in the 2009 PARISE and Spring 2008 PAR experiment will be examined and their responses analyzed in the following sections.

2. DATA

The data used in this study is the open-ended evaluation responses from participating forecasters. This paper explores the responses for a microburst and low-topped tornadic supercell playback case. The responses are used to better understand the impact of high-temporal resolution data on forecasters' decision making processes.

2.1 *Selection Of Participants*

PARISE was one of several experiments taking place simultaneously within the Experimental Warning Program (EWP) of NOAA's Hazardous Weather Testbed (HWT) in 2009 and 2008 (for more information see Stumpf et al 2008). The EWP provides researchers with an opportunity to simulate an operational setting in order to test software and hardware designed to improve warning operations. Forecasters responded to invitations filtered through regional headquarters of the National Weather Service (NWS). Forecasters were brought in for a week at a time, during which they alternated between experiments.

Data analyzed in this study came from the following subset of participants: 10 senior/lead forecasters, 8 Science and Operations Officers (SOO), 6 forecasters, 3 Meteorologists (or Forecasters)-in-Charge, 1 meteorology instructor, 1 journeyman forecaster, and 1 Science Support Division Chief. Years of forecasting experience range from 5.5 to 30. A few teams included non-NWS meteorologists. Two researchers and one PhD student also participated, always on a team with someone from the NWS.

2.2 *Participant Activities In PARISE*

In 2008 and 2009, forecasters were first trained on PAR and PARISE objectives through hand-on experience and training seminars (Heinselman 2009). The participating forecasters looked at both real-time data and archives of simulated playback cases when severe weather did not occur (Heinselman 2008). This study focuses on forecaster evaluation of PAR for two playback cases.

The two playback cases were chosen because they were types of storms common elsewhere and atypical of Oklahoma. Thirty-three participants, at times working alone but usually in teams, evaluated the 10 July 2006 microburst and 19 August 2007 low-topped tornadic supercell case. PAR volumetrically sampled the microburst every 34 seconds and the low-topped tornadic supercell every 43 seconds. Forecaster participants were then asked to analyze the data and issue warnings as part of the simulated work environment; participants were asked to have a mental attitude of actually being on the job during evaluation to further simulate the pseudo-operational experience (Heinselman, 2008). At the end of each event, participants were asked to complete an evaluation questionnaire.

2.3 *Evaluation of PARISE in Simulated Warning Operations*

Heinselman (2008) designed the questions in the evaluation questionnaire to assess strengths and limitations of PAR data as compared to WSR-88D data, how characteristics of PAR scanning strategies affected their interpretation of severe storms, how using PAR data impacted their warning decision-making process, what if any challenges arose from using PAR data, what information would like to be seen in the future that has not been seen from weather radar, and an the overall impression of PAR data usefulness.

The above topics were presented as short-answer, open-ended questions. The advantages to providing open-ended questions allows for more explanatory responses that can contain useful additional information that participants may want to include.

The questionnaire used in the 2008 experiment was slightly modified for use in the 2009 experiment (See Appendix). On the 2008 questionnaire, analysis was done on questions concerning strengths/weaknesses of PAR data (1), scanning strategies assisting or impeding analysis (3), scanning strategy needs (4), the impact of PAR data on warning decision making (5), challenges that may have arose with PAR data during analysis (6), what would like to be seen from weather radar that is not seen now (8), and overall impression of PAR technology (9). Question 3 on the 2008 questionnaire was an additional question asking: *"How did the* *following PAR scanning strategy characteristics* <u>*assist*</u> *or* <u>*impede*</u> *your analysis of storm features?"* The questions from 2009 were the same except for the additional 2008 question, which was a modified but similar version of question 4 from 2008. The questions on Adaptive DSP Algorithm for PAR Timely Scans (ADAPTS) were not analyzed because they were not asked in the questionnaire from 2009.

The evaluation research that was done in this paper differs from traditional types of research. In basic and applied research, the instrument must stay the same because it deals with comparison among participants. This evaluation research study used open-end questioning to understand impacts of PAR on the forecasters decision making processes. We are capturing user input to what would help radar researchers. The process is evolutionary because as the research and development (R&D) is evolving the instrument is slowly adapting due to studying user interactions along the R&D continuum.

3. METHODOLOGY

The responses were first combined into digitized form to begin the process of analyzing the raw data into interpretable information. Following Lincoln and Guba (1985), the data were broken into units ranging from phrases to complete answers to particular questions. The individual unit division was based on its ability to have meaning without the need for additional information. The unitized information was then sorted into categories. The first unit was placed aside and mentally noted of its underlying content then whether the second unit is essentially of similar content as unit 1 determined if it was placed with the first unit or made its own soon-to-be-named category. Successive units are treated the same way. After a number of units were processed, the naming of categories began and new categories developed as more processing occurred. A miscellaneous pile was created for units where to the developing set was determined irrelevant; this pile was then later reviewed.

When a category had a significant number of units, about six to eight, a propositional statement was created, denoting the properties of the units as a category. Inclusion and exclusion rules were then placed on the category as a more concrete mode of deciding whether to place, displace or exclude any given unit.

When all the cards had been sorted, miscellaneous pile was reviewed and placed into the mature categories when possible. All the categories were then reviewed for misplaced cards. If any were found, they were processed. Unassigned units did not exceed the expected 5 to 7 percent of the total (Lincoln and Guba, 1985). Many unassigned units were comments that were unexplained. For example, responses to the question, "*What was your overall impression...?"* included "*very cool*," and "*very impressive*." These responses were unexplained, so could not be assigned to a category.

Categories were founded on what became apparent from the data rather than from preconceived theories. This method of unprompted categorizing is called data-driven or inductive-driven analysis (Boyatzis 1998). Following category formation, relationships between categories were posed and checked against the data. Although initial category formation was based upon the contrasts of positives vs. negatives, a key part of the data analysis involved synthesizing information (Patton 2002).

Credibility of findings was assured by investing ample time into continual checking of categories to make sure the units in a category were cohesive. Analyst triangulation was employed when two of the authors analyzed the dataset and agreed upon the categorization and findings. This study also meets the criteria for judging the credibility of qualitative evaluation research (Patton 2002): accuracy and balance in the presentation of findings, use of a systematic inquiry, respect and fairness to participants, and consideration of the diversity of interests involved in development of future weather radar systems. A further measure will be evident some time later: whether the findings were useful *and* used.

4. FINDINGS

Several principal themes emerged: strengths based on what PAR provided, strengths based on what PAR did not provide, negatives based on what participants got out of PAR that they did not want, and a negative based on what participants did not get out of PAR and desired recommendations. Tables 1 through 5 show the Major Categories, Sub-Categories and the number of units that correspond to the adjacent sub-category. The tables range from positives, negatives and recommendations of PAR participants. All quotes used in this section are examples typical of the units in its category.

Themes are first based on major divisions that were founded upon the differences of positives, negatives and comments about PAR. Secondly, an integration of ideas produced a progression of the impact PAR has on decision making processes.

Table 1.
Strengths based on what PAR provided. The organization is supported by the likely progression of how forecasters issue warnings

Categories	Sub-Categories	# of units
Frequent updates as a strength of PAR data		
	Identify key features	2
	Viewing circulations	5
	Viewing short lived tornados	2
	General cited interests/benefits	17
PAR for tracking genesis and evolution of weather events		
	Microburst	17
	Supercell	16
Easier overall identification of features		
	Microbursts and its associated features	3
	Strong outflow winds	3
	Divergence/convergence	2
	high temporal resolution as positive factor	5
Superiority of PAR over current radar system		
	Feature depiction	
	RFD	3
	TVS	3
	Supercell	2
	Divergence/convergence	2
	Other significant features	6
	High temporal resolution as positive factor	8
High Temporal resolution leading to warnings being issued		
	High temporal resolution as positive factor	13
Greater confidence in what was being seen		
	Seeing and concretely identifying signatures	5
	PAR data reassurance	4
	High temporal resolution	4
Warnings going out in a timely matter		
	Clearly displayed storm structures	5
	Warnings overall went out earlier	2
Warnings due to superiority of PAR over current radar		
	Helped verify warning-worthy features	4
	Strongly impacted warning decision-making	8
Increased/Improved lead time		
	PAR can allow for increased lead times	4
	High temporal resolution	5

4.1 High-Temporal Resolution leads to Greater Continuity of Features and Increased Confidence

Table 1 shows the findings according to the natural progression of the forecasters' warning decision-making process. The progression goes from identifying key features, PAR data validating what forecasters are observing due to clear and constant depiction, confidence is increased due to continuity in scans, confidence in observations leads to warnings being issued earlier, earlier warnings increase lead time. A total number of 150 units represent this derived theme.

Divergence/convergence, cores aloft, and "strong near-surface winds" were identified features of the evaluated microburst case. As one participant stated, "frequency of volume scan updates allowed us to track elevated cores better." The evolution of core descent was depicted well in PAR data according to the participants. A participant replying to the strengths or weakness of PAR data involving microburst wrote, "Rapid updates from PAR helped show quickly evolving storm development and then collapsing cores in microburst environment." Low-level scans could capture supercells in motion and vertical analysis helped participants examine mesocyclone vertical extent. A participant commented on PAR helping with identification, "the rotation was clearly defined and the rapid updates allowed us to quickly observe changes in the vertical."

Some participants recognized the likely tornado in the low-topped supercell case by clear, associated features: TVS, shear, and mesocyclone vertical extent. As one participant commented, "…the TVS signature really stood out." The evolution of the RFD and supercell/mesocyclone circulation also helped. All together 24 units noted seeing the supercell and its associated features.

Seeing the continuity of key features in each case increased confidence. A comment by one participant states, "frequent volume scans gave me more confidence that system was not pulsing," and another wrote a similar response, "Additional data gave me confidence feature was real." PAR seemed to provide reassurance to the forecasting participants.

Warnings were issued once confidence was established. Participants were able to see the weather events earlier and clearer because of the rapid updates of PAR. Warnings were then issued earlier. A participant responded to a question regarding PAR data impact on warning decision making by stating, "Allowed the tornado warning to be issued 3-4min before signature appeared on [the WSR-88D], and with higher confidence." Subsequently, earlier warnings led to increased lead time as reported by a participant, "[PAR data] allowed more lead time due to faster updates and finer resolution"; another wrote, "In my mind, PAR would no doubt increase warning lead time."

4.2 *Human and Computing Limitations*

The theme of problems that can develop from the rapid updates is shown in Table 2. Tools of PAR such as: Warning Decision Support System-Integrated Information (WDSS-II; Lakshmanan et al. 2007) display and CPU were a problem for some participants. The CPU problem is a direct result of the additional power needed to upload and display the numerous scans. As one participant reported, "…WDSS-II made it a challenge to keep [velocity and reflectivity] images coordinated. With time using WDSS-II this became less of an issue" and another stated, "The actual radar was fine but we did have

Table 2.
Negatives based on what participants got out of PAR that they did not want

Categories	Sub-Categories	# of units
Problems using the tools associated with PAR		
	WDSS2	2
	Cross sections/display	2
	Others	2
Influx of data causes feelings of overload		
	Rapid updates as a negative factor	7
	General feelings of overload	3
Projected difficulties using PAR with multiple weather events		
	Potential monitoring difficulty	5
	Choosing what to monitor challenges	2
Cautions toward FAR/self-recalibration/lack of experience		
	Possible increase in FAR	2
	Experience needed	2
	May need recalibration	2

Table 3.
Negative based on what participants did not get out of PAR

Category	Sub-Category	# of units
Areas where PAR and current radar had little distinction		
	Feature I.D.	4
	Both PAR and 88D were lacking	1
	PAR being less than 88D	1

a few problems using the tool like checking the latest scans." The display was noted as a problem for some participants. One participant wrote, "Visualization using CAPPI and cross sections were challenging because of tiny display of that pane. Addressed through better displays."

There were 10 units that included responses about the possibility of feeling easily overwhelmed by the incoming rapid updates. One participant's response was "keeping up with rapid updates could be a challenge." Multiple weather events would be difficult to monitor according to 7 units because of the frequent updates of PAR; a participant said he "Was able to keep up with rapid volume scan updates because only had a few storms to deal with." Participants reported in 6 units, the need for more experience or self-recalibration to avoid a possible increase in false alarm rate (FAR); as one participant states, "Forecasters are typically trained to wait a couple of scans to see if a signature is persistent or real. May need to wait 4-6 scans on PAR. Increase in FAR [false alarm rate] is possible."

Although it did not come up often, PAR was reported as not being much different from current radar systems, PAR lacking some of the same ability as the current radar, or PAR being worse (Table 3). The participant that thought reflectivity was underestimated by PAR relative to KTLX, the local WSR-88D stated, "Similar to 88D showing lack of hail potential, as well as features in precipitation field."

4.3 *Desired Radar Characteristics*

Twenty-nine units mentioning integrations that would have liked to be seen in PAR is shown in Table 4. A more customizable tilt variety was a reported desire, especially with low level scans. The response for one participant was "For storms in closer to the radar – add more slices up high. Storms further out – more slices down low would be helpful. This would especially true probably in mountainous areas where surrounding radars may not be as useful due to blockage as compared to lower elevation areas." The participants would have wanted more options such as dual polarization, more control in general, but some noted wanting more control over scans and more range in the scans rather than the 90º sections the participants had to work with. As a participant stated, "Of course it would be nice to see 180 degrees. Also, ultimately, it might be nice to have some control over this to adapt to the particular situation."

The limitations of current radar that is a strength of PAR was categorized (Table 5). Current radar has slow scanning speed and fewer low-level scans but PAR does not. Some participants stated that they saw no real challenges with PAR data. There were 10 units in this category.

Table 4.
Desired recommendations for weather radars

Categories	Sub-Categories	# of units
Wider variety of tilts		
	More low-level scans	9
	More high-level scans	4
	More of both	1
Notable Wants		
	Dual-polarization desired	4
	More control	2
	More options	6
	Larger range scan from PAR	3
Strengths/limitations of current radar		
	Velocity data as strength	4
	Reliable	2
	Other strengths	2
	Strength question unanswered	2
	General limitations	4

Table 5.
Strengths based on what PAR did not provide

Categories	Sub-Categories	# of units
Forecasters seeing no problems		
	Scan Strategy	4
PAR does not possess some of the limitations of current radar		
	Scanning speed	5
	Amount of low-level slices	1

5. DISCUSSION

Several sections will be reviewed here to clarify information that was mentioned earlier. This section is meant to provide full disclosure of otherwise obscure details. Caveats, explanations and recommendations for future research will be discussed further.

5.1 Findings

PAR validating through clear depiction and warnings being issued earlier are statements from the findings for Table 1. The clear depiction that was discussed is a direct result of the high spatial and temporal resolution of PAR data. Warnings being issued earlier comes from the frequent updates of PAR. The faster the updates the quicker forecasters can see clearly depicted key features causing warnings to go out sooner. As a participant already mentioned, the extra data assured that the feature was "real" which boosted confidence.

Some comments were geared toward problems with the WDSS-II software that is used with PAR. WDSS-II was used instead of traditional Advanced Weather Interactive Processing System (AWIPS) because AWIPS updates scans in the order of minutes but PAR data comes in the order of seconds and because of the layout of WDSS2 the display size condensed the image size of WDSS-II making images difficult to see.

As stated in the findings some participants believed that working with multiple storms at once would be an issue to work with because of the frequent updates. As a suggestion for future evaluation within PARISE many different weather events should be introduced to participants to see if they actually would have trouble keeping up what the technology.

In the description of Table 5 participants reported wanting more control over scans and a higher scanning degree out of PAR. What was not reviewed by the participants was the scanning strategy of ADAPTS. ADAPTS allows for more control and variety but scanning only areas of interest. It also gives users the option of turning the technology off and on. The sector size of PAR is limited now because it is a prototype research radar with only one phased array antenna. The future development of PAR includes a four phased array antenna arrangement that will provide full 360º scans.

5.2 Cases

The tornado case had 19 reviewers and the microburst had 11, but comments did not appear to overemphasize the tornado case. This may be due to the higher number of features being considered to identify a microburst. Microburst processes encompass the entire storm lifetime, which is short, and analysis emphasizes the entire volume of the storm.

These two cases were types of events where the fast scanning of PAR could potentially make a difference in warning decisions. The fast scanning of these storms better captured evolution and key associated features. Researchers may wish to include a broader spectrum of events, as is possible, in future evaluations.

5.3 Participants

The participant pool was not characteristic of average warning forecasters. SOOs, senior or lead forecasters, and managers were present in high numbers compared to other titles such as forecaster. At this stage in the research and development process, it may be advantageous to bias the participant pool toward experienced forecasters who bring a wealth of experience and perspectives to the project. In the later phases of user evaluations of PAR, however, the participants should resemble what is typical of average warning forecasters to understand the impact and readiness of the field for this technology. A participant stated, "[I] could see rapid updates of data overwhelming forecasters (some of them) without adequate training." Using a more accurate spectrum of participants can test this presumption. Researchers need to explore this aspect of user reaction to assure the resulting technology, once deployed, is the most usable tool.

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