Considerations for Phased-Array Radar Data Use within the National Weather Service

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ABSTRACT

Thirty National Weather Service forecasters worked with 1-, 2-, and 5-min phased-array radar (PAR) volumetric updates for a variety of weather events during the 2015 Phased Array Radar Innovative Sensing Experiment. Exposure to each of these temporal resolutions during simulated warning operations meant that these forecasters could provide valuable feedback on how rapidly updating PAR data impacted their warning decision processes. To capture this feedback, forecasters participated in one of six focus groups. A series of open-ended questions guided focus group discussions, and forecasters were encouraged to share their experiences and opinions from the experiment. Transcriptions of focus group discussions were thematically analyzed, and themes belonging to one of two groups were identified: 1) forecasters' use of rapidly updating PAR data during the experiment and 2) how forecasters envision rapidly updating PAR data being integrated into warning operations. Findings from this thematic analysis are presented in this paper, and to illustrate these findings from the forecasters' perspectives, dialogue that captures the essence of their discussions is shared. The identified themes provide motivation to integrate rapidly updating radar data into warning operations and highlight important factors that need to be addressed for the successful integration of these data.

1. Introduction

The Phased Array Radar Innovative Sensing Experiment (PARISE) has completed four main studies to measure the impacts of rapidly updating phased-array radar (PAR) volume scans on National Weather Service (NWS) forecasters' warning performance and related warning decision processes during a variety of weather events (Heinselman et al. 2012, 2015; Bowden et al. 2015; Bowden and Heinselman 2016; Wilson et al. 2017). In previous studies, forecasters were exposed to only 1- or 5-min PAR updates. Although these studies demonstrated positive impacts of 1-min PAR update use on forecasters' situational awareness, applications of conceptual models, and the accuracy and timeliness of the warnings (e.g., Heinselman et al. 2015; Bowden et al. 2015), forecasters' experiences were constrained to a single temporal resolution of radar data.

The 2015 version of PARISE was unique in that all 30 participating NWS forecasters were exposed to three temporal resolutions of PAR volumetric updates. The opportunity to actively work with multiple radar update speeds meant that these forecasters were positioned to provide well-balanced feedback on what they considered to be the operational impacts of rapidly updating PAR data. This feedback is important for informing future technology decisions and ensuring that their needs as users will be met should rapidly updating radar data become a reality in future warning operations. Six focus groups were therefore conducted to enable forecasters to share their feedback and offer valuable insight from the 2015 PARISE.

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a. Experiment description

In the most recent PARISE, 30 NWS forecasters were each invited to participate in one week of the experiment, which took place in the NOAA Hazardous Weather Testbed over six weeks during August and September 2015. The experiment week that participants were assigned to only depended on their availability. The participants were recruited from 25 forecast offices located in the Great Plains, and their forecasting experience ranged from 1 to 27 yr (mean = 12 yr, standard deviation = 7 yr). Throughout the week, forecasters worked a series of nine weather events, of which three were considered null, three presented severe hail and/or wind threats, and three presented tornado threats. The duration of each simulation ranged from 19 to 65 min. Forecasters were asked to independently interrogate reflectivity, velocity, and spectrum width products in simulated real time and issue severe thunderstorm and tornado warning products as they considered them necessary. For each case, forecasters were provided with either 1-, 2-, or 5-min PAR volumetric updates depending on their random assignment to one of three groups. All groups rotated through each temporal resolution for the three null events, three severe hail and/or wind events, and three tornado events [see Wilson et al. (2017) for further details].

b. Focus group description

At the end of each of the six experiment weeks, a focus group was conducted that consisted of five participating forecasters, all of whom were from different forecast offices. Given that the focus group was the final activity of the week, both forecasters and researchers had already established rapport, thus encouraging honest and fruitful discussions. The focus groups were guided with a set of predetermined open-ended questions so that forecasters' responses were unconstrained (Lazar et al. 2010). These questions were specifically designed with a goal of eliciting feedback on forecasters' reactions and responses to the three temporal resolutions of PAR data, how these data affected their conceptual understanding of different weather events, and how they envision using these data in a real-time operational environment (see the appendix for list of questions). Although the flow of discussion differed for each focus group, all participants were asked the same set of questions and discussions lasted between 1.5 and 2 h. An advantage of collecting forecasters' feedback within a focus group setting was that interactions between participants helped create a synergistic effect, which in turn promoted the sharing of opinions and the generation of ideas (Cameron 2010; Krueger and Casey 2015).

In this article, we present the findings from the analysis of the forecasters' feedback. Transcriptions of the six focus group discussions were thematically analyzed according to their semantic content (Clarke et al. 2015). A list of codes was first developed to describe the content, and these codes were then reduced to a set of themes that belonged to one of two groups (Fig. 1). Given the qualitative nature of focus groups, findings related to the identified themes are expressed in impressionistic terms and are based solely on the viewpoints of forecasters participating in this study (Cameron 2010). To ensure anonymity in direct quotes, forecasters were assigned participant numbers P1–P30. This article describes each of the identified themes and shares the most inclusive and pertinent topics that forecasters discussed.

2. Using rapidly updating PAR data during the experiment

a. Reactions to radar update times

For all participating forecasters, their first opportunity to use rapidly updating PAR data to make warning decisions was during this experiment. Describing their initial reactions to these data, forecasters focused on 1-min PAR updates and exhibited positive and upbeat attitudes because of their ability to now view how storms were evolving on shorter time scales. General statements were made, such as ''It was awesome. I know this is happening, but I can't see it with the 88D data. You miss everything in between'' (P21). Some forecasters also likened these data to textbook examples of storm processes and pointed out that ''With the one-minute data it looks more like what you see when you are out in the field'' (P5).

Forecasters viewed these faster updates for three of nine cases that were worked in a randomized order and became used to the additional radar data very quickly. As P27 reported, their randomized case order meant that they worked three weather events with 1-min PAR updates first. P27 noted that that they ''got used to the fast data fast,'' such that returning to 5-min PAR updates ''Killed me. . . . It was like walking through wet cement and I wanted faster data.'' Though the case order for other forecasters did not accentuate the difference between 1- and 5-min PAR updates as much, they still became accustomed to the faster updates quickly, making statements that they were ''waiting for data when I had slower data'' (P8), which ''was like watching paint dry'' (P24). Thinking about their return to the forecast office, P27 said that they ''can already tell that this is going to kill me during my first radar shift. I will just want the [faster] data!''

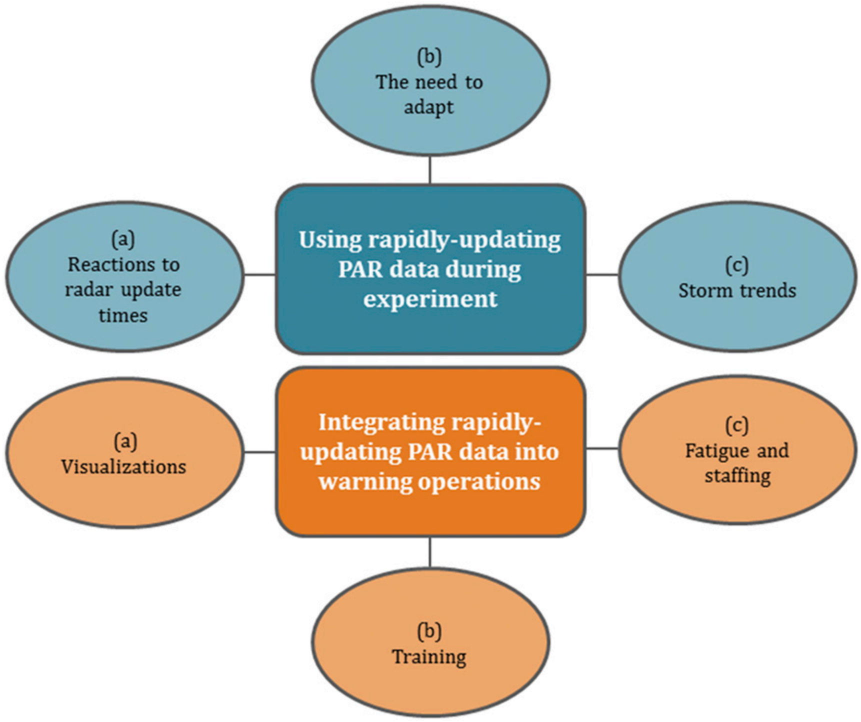

FIG. 1. Two groups of themes identified in transcriptions from forecasters' discussions during focus groups.

Another point of discussion regarding forecasters' reactions to faster radar updates was how their sense of time became skewed. One participant pointed out that ''You see a new scan and think it has been five minutes,'' (P27) while another noted that ''With one-minute [updates], time seemed like it was going faster than it actually was'' (P9). Forecasters evidently use radar updates as an external cue for time progression during warning operations and were either unaware of how strong this external influence is on their sense of time or were not actively prepared to shift their sense of time during this experiment.

b. *The need to adapt*

Despite forecasters being excited about the use of 1-min PAR updates to make warning decisions, approximately one-third of participants reported feeling overwhelmed at first. This feeling resulted from trying to ''keep up with everything coming in'' (P19) and ''look at all tilts of everything'' (P15) at the same rate that the faster updates were being received. These participants reported that they soon realized interrogating faster updates in this manner ''was not going to be possible'' (P15). P8 explained that ''It was nice to see all of the data, but to not become overwhelmed you had to quickly go through stuff and decide what you actually wanted to look at.'' Forecasters therefore described needing to use a ''mental filter'' (P11) that was dependent on ''the threat type and what your expectations are'' (P25) to better manage the increased amount of radar data. Applying a mental filter was most necessary during weather events that posed a tornado risk. Like many other forecasters, P2 explained that they ''Pushed hail aside and just watched 0.5 velocity like a hawk'' believing that it was ''worth the trade off since you need to know about the tornado.'' However, several participants cautiously added that this prioritization in attention should depend on the seriousness and location of threats. For example, P3 pointed out that ''If there is softball size hail over a town, you need to be looking aloft for the hail cores. Especially if the tornado is weak and in a rural area and the big hail or wind is in a town.'' Therefore, focusing interrogation according to the primary threat may not always be an ideal solution for comfortably managing faster radar updates.

c. *Storm trends*

When discussing the specifics of the cases worked, forecasters focused heavily on their newfound ability to observe storm trends in much greater temporal detail when using faster radar updates. These forecasters explained that they ''Have more confidence when you can see evolutionary changes [because] you see what you are expecting to see, or maybe what you were not expecting to see'' (P20). Many of their shared examples from the experiment corroborated findings from earlier PARISE studies and drew on some of the previously reported sampling limitations of the Weather Surveillance Radar-1988 Doppler (WSR-88D; LaDue et al. 2010). For example, in pulse-type storm environments, forecasters appreciated being able to better observe the persistence of updrafts as well as track the development and location of high-reflectivity cores. Like others, P27 thought that ''it was really cool to see the new updrafts form aloft. It was awesome to have fast data there. With five minute data a storm could pulse up and you won't even see it. So you could see your conceptual model evolve over time instead of making assumptions.'' Similarly, P9 said that ''You can see so many more features. You can see the high reflectivity cores grow elevation scan to elevation scan. With the 88D it just shoots up, you know it increases, but you don't get to see it happen.'' Additionally, being able to see hail cores ''descend minute by minute down to the surface'' aided forecasters in modifying the expected weather threat after a warning was issued, allowing them to ''put out an update and call for bigger hail'' (P23).

Forecasters also described the usefulness of faster radar updates for making tornado-related warning decisions during this experiment. In simulated warning operations, viewing radar-indicated evidence of tornadogenesis in finer temporal detail has resulted in the issuance of earlier warnings by up to 7.5 min, especially during classic supercell events (Heinselman et al. 2015; Wilson et al. 2017). In the 2012 PARISE, forecasters achieving above-average tornado warning lead times applied conceptual models that depended on trends only observable in the 1-min PAR updates (Heinselman et al. 2015). P13 emphasized the importance of these trends, reporting that ''I've never seen such a clear example of tornadogenesis in radar data before. You see the rear-flank downdraft kicking out, the midlevel meso dropping down. You saw what you would expect to see based on the textbook conceptual model. You could not see that with five minute data. I am confident that this allowed me to put a warning out sooner than with five minute data.'' Despite these encouraging results, the most recent PARISE also found that extending tornado warning lead times through the use of faster radar updates was difficult to achieve for a weak and short-lived tornado that developed in a quasi-linear convective system (Wilson et al. 2017). Based on their use of rapidly updating radar data for this single event, some participants explained that while 1-min PAR updates allowed them to observe brief circulations, it was unlikely that they would issue a tornado warning. Some forecasters reasoned that ''The fastest you can issue a warning is a minute or so, and by then the warning is out and not much is happening'' (P18). Nevertheless, forecasters did state that being able to observe these circulations was still beneficial for providing additional threat information in a severe thunderstorm warning.

Observing more-detailed storm trends was also helpful in preventing the issuance of warnings on storms that did not become severe. Forecasters reported being able to see that storms ''Never really got a great updraft for what I would think is needed to get a good downburst'' (P10) and that cores ''Were not sustaining themselves for very long'' (P7). While these observations did help reduce the number of false alarms in the 2015 PARISE (Wilson et al. 2017), a handful of forecasters noted that ''You have to be careful with how quickly you react to the one-minute data too'' (P11). Several forecasters using faster radar updates were disappointed in impulsive warning decisions made after viewing intensifications in storm trends that were only transient and, therefore, recommended waiting to view consistency in trends before acting on them.

3. Integrating rapidly updating PAR data into warning operations

a. Visualizations

To create a mental image of storm structure and trends, forecasters currently analyze the vertical profile of storms in separate elevation scans and step back and forth in time to assess the temporal changes. This approach was found to be time consuming when using 1-min PAR updates during the experiment, leaving some forecasters feeling overwhelmed and many needing to limit their attention to portions of the storm that they believed posed the greatest threat. Forecasters identified that ''The answer to data overload might be integration in a 3D display, like GR [Gibson Ridge] or FSI [Four-Dimensional Stormcell Investigator]. . . . With the 5-minute data, I don't feel like cross sections or volume data is really that helpful, but with this data I could really see myself using those types of tools'' (P27). Furthermore, forecasters want trends to be monitored using an automated technique. P18 suggested that ''If AWIPS could somehow track a core and tell you how much the reflectivity is changing from scan to scan, you don't have to look and calculate for yourself. Something could tell you that the reflectivity has increased by 40 dBZ.'' This idea would reduce the manual search efforts and corresponding demand on working memory for tracking trends and could be extended to monitoring additional aspects of reflectivity cores, as well as the evolution of other precursor signatures.

b. *Training*

Forecasters drew on their experience of using faster radar updates to make recommendations for the type of training they would find most helpful, and unanimously agreed that hands-on experience is most valuable. Though not possible in PARISE, forecasters felt it would be advantageous to work weather events multiple times with different temporal resolutions of radar data. This activity would allow them to better assess how faster radar updates can benefit their warning decision process. As P25 pointed out, ''I don't know what I missed between scans.'' Given that you ''Can see a lot of new processes'' (P2) that were previously unobservable, some forecasters suggested that providing a list for when faster radar updates are most beneficial to the warning decision process would also be helpful. Furthermore, forecasters noted that the greater temporal detail in storm processes will require them to revisit and possibly modify their conceptual models. One forecaster suggested that showing ''Video of the storm alongside the radar so people can get used to seeing how the storm evolves and what that looks like on radar'' (P25) would aid this process, while another noted the importance of interrogating faster radar updates using ''Only base data without algorithms [to]. . .force you to go back to conceptual models'' (P8). Forecasters suggested completing hands-on training away from the forecast office in a setup similar to the Warning Decisions Training Division's Radar Applications Course. This idea was preferable to within-office training because ''There are many more distractions'' (P29) within the forecast office and ''Sometimes it takes two months just to get everyone in the office through one case'' (P3). Recognizing that resource limitations may make this idea difficult to execute, one feasible suggestion was that ''You need to train the trainer. Bring one person from each office and then have them go back and teach the office'' (P4). The NWS Training Center recently adopted this strategy for the Geostationary Operational Environmental Satellite-R series (GOES-R) preparation course, in which science and operations officers and development and operations hydrologists developed knowledge and experience that could then be shared with forecasters at the local level (B. Carcione 2017, personal communication).

In addition to receiving hands-on training, forecasters thought that step-by-step reviews of their own warning decision processes would be a useful training activity. As part of this experiment, forecasters were asked to watch a playback video of their onscreen activity and recall what they were seeing, thinking, and doing. P22 suggested ''What if at every office you sat people down and asked them what they were thinking minute by minute. Maybe we can improve what you are doing. . . . That was helpful for me, since I have never been asked this before.'' While most other forecasters agreed with this statement, a few felt that reviewing onscreen activity in this manner might make others feel as though their warning decisions are being judged. Importantly though, P25 emphasized that ''We need to be more thick skinned as a weather community with case reviews. What we have done this week is one step away from what an NFL team does each Monday when they dissect game film.'' Forecasters therefore recognized that this review procedure would be a useful training approach for strengthening the performance of both the radar operator and forecast team as they learn to integrate faster radar updates into warning operations.

c. *Fatigue and staffing*

Ensuring that humans are operating within their optimum working conditions is important for both their well-being and their performance. While cognitive workload associated with the use of rapidly updating PAR data has been assessed within the PARISE setting (Wilson et al. 2017), it has not been measured in live operations where forecasters are part of a team and are exposed to many other data sources. Some forecasters expressed their concern about the ''fatigue factor,'' where ''It would be a bigger factor with rapid-update data since you are interrogating more data. . . . We are already concerned about that. We talk about it every spring. How long are we going to let someone look at radar data? With new types of radar data, that conversation is important again'' (P21). Reflecting on this matter, forecasters stressed that to work efficiently with faster radar updates and to ensure smooth function of warnings operations, they would need to redistribute responsibilities within their teams. Forecasters expect that ''There will be an increasing need to sectorize'' (P17), meaning that ''There will need to be more radar operators'' (P9). Additionally, forecasters recommended sharing the task of updating warnings so that the radar operator could focus on issuing warnings only.

4. Discussion and conclusions

Communicating findings from the focus group discussions gives forecasters a voice in the research process and allows for an evaluation of rapidly updating PAR data from their specialized perspectives. The six focus group discussions brought attention to the ways in which forecasters felt these data benefited their warning decision processes and highlighted some important considerations that need be addressed should these data be implemented operationally.

The consensus among forecasters was that 1-min PAR updates are preferable to 2- and 5-min PAR updates. This preference was further evident in their choice to emphasize and share experiences that were predominantly related to their use of 1-min PAR updates during the experiment, with little to no attention given to their use of 2-min PAR updates. Forecasters' lack of comments regarding 2-min PAR updates was surprising given other forecasters' suggestions in earlier studies that it would be helpful to show 2-min PAR updates in addition to 1-min PAR updates (Bowden and Heinselman 2016). However, capturing the feelings of others, P25 summarized that ''At the end of the day, radar data is the heart and soul of warning operations. If it stops, you are severely handicapped. So, it is critically valuable, especially if it is one minute, because it is giving you a constant idea of what the storms are doing and where the storm is and where it is moving and where it has been. It has to be integrated in some way, shape, or form.''

Despite strong consensus that forecasters preferred the use of 1-min PAR updates, some disagreement in how to manage these data emerged in the focus group discussions. First, while numerous forecasters thought that the development of new algorithms could provide a solution to the increased levels of workload associated with tracking 1-min trends in radar signatures, others expressed concern that forecasters might become dependent on these algorithms and lose their sense of conceptual understanding. Second, many forecasters found that prioritizing attention to the primary severe weather threat helped counteract high levels of workload. However, several forecasters thought that this approach was not suitable for dealing with scenarios that presented multiple weather threats. Future research efforts should examine the feasibility of these suggested solutions in an experimental setting where the impacts of algorithm use and prioritization of attention on forecasters' warning decision processes can be assessed independently.

In addition to forecasters' suggestions of employing new strategies for viewing 1-min radar updates, being able to successfully alleviate the inevitable increase in radar operator demands will depend on the ability of forecast office staff to redistribute responsibilities. During the 2015 PARISE, forecasters reported experiencing levels of high and excessive workload more frequently when using 1-min PAR updates during events that presented a tornadic threat (Wilson et al. 2017). Oftentimes, this spike in cognitive workload occurred during times in which forecasters were issuing or updating a warning, which led to forecasters' recommendation that sharing product issuance tasks among multiple radar operators would be one helpful approach to decreasing cognitive load. Furthermore, during weather events that are more demanding on forecasters' attention, the presence of multiple radar operators would be beneficial for sectorizing warning areas and reducing an individual forecaster's overall task load.

Forecasters' positive attitudes and outlooks of using rapidly updating PAR data within the forecast office are encouraging. Successful implementation of rapidly updating radar data will first require the delivery of hands-on training. Because logistical limitations will likely prevent all forecasters from completing a course at a training center location, an approach similar to the GOES-R preparation course is recommended. In this instance, specific individuals from forecast offices receive specialized training and transfer their learned knowledge and skills to other forecasters upon their return. Additionally, given that many forecasters commented on the usefulness of completing retrospective recalls during the 2015 PARISE, we believe that adopting this practice as a form of training will enhance forecasters' capacities to understand and improve upon their own warning decision-making behavior. Although some forecasters expressed frustration at finding the time to complete training during work hours, in-house training must become a priority to ensure a smooth transition to using rapidly updating radar data in warning operations.

Although forecasters have not yet used 1-min PAR volumetric updates during real warning operations, their use of the recently implemented Multiple Elevation Scan Option for Supplemental Adaptive Intra-Volume Low-Level Scan (MESO-SAILS) scanning strategy could provide some interesting insight for the potential integration of PAR data in the future (Chrisman 2014). MESO-SAILS allows forecasters to receive up to three additional interspersed 0.5°-elevation scans during a volumetric update. While this scanning strategy does not mimic the rapid updates that PAR obtains for the entire volume scan, a review of the initial impact of these more frequent low-level observations on forecasters' warning performance should be completed. This review would be a first step to investigating some of the focus group findings in real-time operations. Forecasters indicated that responding too quickly to transient trends in radar signatures could negatively affect their warning decisions. Assessing forecasters' use of MESO-SAILS within operations with respect to their reactions to trends viewed in the 0.5°-elevation scan would thus be worthwhile. Additionally, given that forecasters in the focus group described experiencing a skewed sense of time while interrogating 1-min PAR updates, it would be interesting to explore whether forecasters using MESO-SAILS within the naturalistic environment also need to modify their sense of time when consistently tracking the 0.5°-elevation updates. Finally, important lessons could be gained from investigating the overall implementation of MESO-SAILS into the forecast office, the preparations that forecasters found helpful prior to their use of these additional data, and how they adapted their interrogation styles to effectively incorporate these data into their warning decision processes.

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APPENDIX

List of Questions Used in the Focus Groups

1) What was your first reaction to the 1-min, 2-min, and 5-min PAR update times?
2) How did your reactions to the 1-min, 2-min, and 5-min update times impact your interrogation strategies when working what you believed to be a a) severe hail and wind event, b) tornado event, and c) nonsevere event?
3) Did you have a difference in understanding of what you believed to be a a) hail and wind event, b) tornado event, and c) nonsevere event based on the temporal resolution of PAR data available?
4) Imagine you are going back to your office and you have rapid-update PAR data (1-min or 2-min updates) like you had here. Based on your 2015 PARISE experience, what concerns do you specifically have about using rapid-update PAR data in an operational sense?
5) Drawing from your 2015 PARISE experience, what kind of training do you think you would find useful in transitioning rapid-update PAR data into operations?
6) Imagine you are going back to your office and you have rapid-update PAR data (1-min or 2-min updates) like you had here. Based on the 2015 PARISE experience, how do you envision these radar data being integrated into your fuller warning decision process where you have your normal available data and are working with your colleagues?
7) What other thoughts or ideas from the week would you like to share with us?

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