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Results from the Hazardous Weather Testbed: What do Forecasters Think About Dual-Polarization Phased Array Radar?

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Contents

1. Executive Summary

The current National Weather Service (NWS) operational radar network has provided high-quality data for decades. As the need to replace this radar network increases, the NWS is currently assessing options for the next operational radar network. However, there is a need for information, including feedback from the NWS forecasters who use the data on a day-to-day basis, to select the best possible replacement option. One potential option is phased array radars (PAR). Therefore, researchers at the National Severe Storms Laboratory (NSSL) are conducting Hazardous Weather Testbed (HWT) activities with NWS forecasters to gather their feedback on PAR and the current operational network of dish-based radars, known as the Weather Surveillance 1988-Doppler (WSR-88D) radars.

Results from these HWT activities show that forecasters overwhelmingly prefer using PAR over the current operational radars. This preference arose from the rapid volume update times (~1.2–1.8 min), rapid 0.5° elevation angle update times (~20–60 sec), and denser vertical coverage the PAR data provided. These factors allowed the forecasters to better and more quickly identify and understand key radar features that are used to diagnose storm severity. As a result, they could better observe their conceptual models and spend more time critically thinking about the storm and its hazards rather than reacting to the latest scan, something they sometimes have to do with WSR-88D data. The preference for PAR over WSR-88D data exists despite the PAR data forecasters worked with during the HWT activities having a wider beamwidth and reduced velocity data quality compared to the WSR-88Ds. Forecasters also indicated having higher warning confidence while using PAR compared to the WSR-88D.

A majority of, though not all, HWT forecasters voiced concerns regarding the sheer amount of data provided by PAR and the potential for “data burnout” from processing much more data than what is required with the WSR-88Ds. However, many of those forecasters quickly adapted their workflow to the PAR data and tended to feel less overwhelmed by the end of the HWT week. Overall, despite some data workflow concerns, HWT forecasters frequently described PAR data as a “game changer”, “eye opening”, and “invaluable”.

2. Background and Motivation

Weather radar has and continues to supply National Weather Service (NWS) forecasters, convection-allowing models, and severe-weather algorithms with crucial information that allows forecasters to provide the public with the best severe weather warnings in the world. Over the decades, a steady march of radar improvements, such as Doppler and dual-polarization (dual-pol) capabilities, have helped facilitate advancements in severe weather warnings and understanding. Today, the NWS is looking into replacing the current operational Weather Surveillance Radar-1988 Doppler (WSR-88D; Crum and Alberty 1993) network, and this replacement provides an opportunity to continue pushing operational weather radar technology forward.

One potential step forward is phased array radar (PAR) technology. Instead of having to mechanically steer a radar beam, as is the case with the current operational dish antenna network, PAR technology allows for the radar beam to be formed and steered electronically. This electronic beam steering eliminates the need for moving parts and allows for greater flexibility with the radar system. Concepts such as rapid-update volume scans (Alford et al. 2024, 2025) and adaptive scanning (e.g., Torres et al. 2016), where the radar can focus attention on the most important aspects of a given storm, are possible due to this greater flexibility. In light of the potential operational benefits offered by PAR, the National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory (NSSL) has and is currently conducting research to explore the impacts of PAR data on NWS forecasters through various projects including those taking place in the Hazardous Weather Testbed (HWT).

Previous HWT activities examining NSSL's single-pol PAR (i.e., Zrnić et al 2007) between 2010 and 2015 found:

1) Some pieces of a forecaster's severe weather conceptual model (e.g., tightening of a mid and low-level mesocyclone) are likely not adequately observed by the WSR-88D's volume update time because these pieces evolve over time scales of less than five min (Heinselman et al. 2015).
2) Rapid update volume scans allowed forecasters to more easily see trends in storm intensity and better confirm or reject their conceptual model compared to slower volume update times. This improved understanding allowed them to make more confident and correct (i.e., a warning was verified with the occurrence of severe weather) decisions (Bowden et al. 2015; Bowden and Heinselman 2016; Wilson et al. 2017b).
3) Rapid-update volume scans increased warning lead time by several minutes compared to slower volume update times (Bowden et al. 2015, Wilson et al. 2017a).

The results of these HWT activities certainly remain relevant today, but with the completion of the dual-pol upgrade to the WSR-88Ds in 2013, there is a need to examine the impacts of dual-pol PAR data on NWS forecasters.

Scientists at NSSL and the Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO) are currently working with the first dual-pol, S-band, PAR for weather observations, known as the Advanced Technology Demonstrator (KATD; Torres and Wasielewski 2022). The KATD is a proof-of-concept research radar and therefore is not intended to replicate or demonstrate the capabilities of a potential future operational weather radar network. For example, the KATD has a wider beamwidth, lower sensitivity, and noisier velocity data than what an operational PAR would likely have. Researchers have collected hundreds of hours of KATD data in the past two years (Alford et al. 2024, 2025), and these data allow for multiple lines of research including use with NWS forecasters to answer key questions including:

1) How does dual-pol PAR data impact forecaster understanding, confidence, and decision making during various severe weather events?
2) What aspects of PAR data do forecasters think might be most impactful to them during various severe weather events?

Therefore, the purpose of this research is to examine the impact of dual-pol PAR data on forecaster understanding and decision making during severe weather events through two HWT activities. During activities in August 2024 and February 2025 (section 3) forecasters provided feedback on multiple aspects of radar data—including update time, vertical coverage (i.e., number and spacing of elevation angles), and dual-pol data clarity/texture (i.e., degree of noisiness in the data)—via surveys and focus group discussions (section 4). We also share forecaster thoughts on various aspects of PAR data and workflow (Table 2–7) and combine those thoughts with a quantitative analysis of radar signatures used in the HWT (section 5).

3. PAR HWT Activity Design and Methods

To address our key questions, we designed two different HWT activities that centered around gathering forecaster feedback before, during, and after simulated severe weather warning operations. User feedback data was collected via surveys and focus group discussions. The first activity occurred over three weeks in late July and August of 2024 and the second occurred over three weeks in February of 2025. Four NWS forecasters participated each week in the 2024 activity and six NWS forecasters participated each week in the 2025 activity. Between the two activities, 30 forecasters each worked nine different severe weather events in simulated real time (Table 1), took 10 surveys, and participated in eight focus group discussions. We relied on previous HWT activities (e.g., Heinselman et al. 2015; Wilson et al. 2017a; Calhoun et al. 2021; Sandmæl et al. 2023) and research on forecaster decision making (e.g., Doswell 2004; van Gog et al. 2005; Morss et al. 2015) to guide the design and methods of this HWT activity, with modifications made as needed to best address our research questions.

During the simulated severe weather operations, we asked forecasters to issue severe thunderstorm and tornado warnings while working each case just like they would if they were working the event in real time at their home forecast office. Forecasters used the Advanced Weather Interactive Processing System (AWIPS) and Gibson Ridge Level 2 Analyst (GR2Analyst; https://www.grlevelx.com/)—two software platforms frequently used during real-time warning operations—to view and interact with radar and other meteorological data. Forecasters also used the operational Warning Generation (WarnGen) software to issue all warnings during the week. This setup resulted in a quasi-realistic operational environment and mindset for participants to draw from when providing feedback. To generate additional discussion and aid in memory recall during the focus groups (e.g., van Gog et al. 2005), we asked forecasters to take screenshots of noteworthy radar signatures and data they encountered while working the cases. To drive discussion and collect information during the cases, we frequently asked forecasters questions about what they were seeing, thinking, and doing during the August 2024 HWT activity. However, participants reported that this frequent interaction with researchers sometimes disrupted their normal process of interrogating radar data and caused them to feel overwhelmed at times. Thus, we adjusted procedures for the February 2025 activity. Instead of frequently interrupting participants' workflow with questions, we instead had them fill out a simple warning confidence spreadsheet (Fig. 1) with a self-reported confidence level for each warning and some brief notes about that warning.

Warning Confidence Ratings:				
1	**2**	**3**	**4**	**5**
Not at all confident	**Not very confident**	**Somewhat confident**	**Very confident**	**Extremely confident**
	Monday Training			
Approximate Warning Issuance Time (UTC)	**Warning Type**	**Warning Decision Confidence**	**Notes**	
2120	Sever…	4 - Very …	Z core pulsed up and hit threshold	
2205	Tornado	4 - Very …	RFD surging, rotation tightening	

Figure 1. Example of warning confidence Google sheet HWT forecasters filled out with basic information about approximate warning issuance time, the warning type (severe thunderstorm or tornado), their warning decision confidence level from 1 (not at all confident) to 5 (extremely confident), and any optional notes they wished to include.

3.1 Weekly Structure

Our HWT activity weeks began with a tour of the KATD followed by a presentation with basic information about PARs, what to expect when working with KATD data, and overall goals and logistics of the HWT activity. Forecasters then had time to create procedures in AWIPS that they used throughout the week. Each forecaster then worked through a training case to get familiar with the KATD data, practice issuing warnings, further modify AWIPS procedures, and practice completing other required tasks (e.g., taking screenshots). The forecasters then worked their first true simulated severe weather event Monday afternoon.

Forecasters worked a wide variety of severe weather events over the next three days (Table 1). Each session (i.e., morning or afternoon) contained one or two cases. Forecasters completed an end-of-case survey after working every case and participated in a focus group discussion at the end of every session. We used different session structures to ensure that forecasters had ample opportunities and experiences to provide feedback on PAR (Table 1). For example, in the Monday afternoon and Tuesday morning sessions, forecasters worked only with PAR data. In the Tuesday afternoon and Thursday afternoon sessions, forecasters worked the exact same case back-to-back. Half of the forecasters were randomly assigned to work with WSR-88D data and the other half with PAR data during the first run-through of the case and then each forecaster switched radars for the second run-through of the case. In the Wednesday morning and afternoon sessions, forecasters worked similar cases back-to-back. In August 2024, all forecasters worked with WSR-88D data for the first case and then PAR data for the second case. In February 2025 half of the forecasters were randomly assigned to work with WSR-88D data and the other half with PAR data during the first case, and then each forecaster switched radars for the second case. The Thursday morning session contained only PAR data and focused on decision support services (DSS). Forecasters split into two-person teams, where one forecaster issued warnings and the other provided DSS for a hypothetical outdoor event with thousands of attendees. The DSS forecaster communicated storm hazard and timing info via Slack to a researcher playing the role of a local emergency manager on site at the outdoor event. The week ended on Friday after forecasters completed an end-of-week survey and focus group.

Session (Day and Time)	Storm Mode	Case Structure (Feb. 2025)
Monday afternoon training	Supercell	• All forecasters worked with PAR • Practiced with data
Monday afternoon	Multicell	• All forecasters worked with PAR
Tuesday morning	Multicell	• All forecasters worked with PAR
Tuesday afternoon	Supercell	• Exact same case worked back-to-back. • Forecasters randomly assigned radar for first case run-through • Switched radar for second run-through
Wednesday morning	Mesoscale convective system	• Two similar cases worked back-to-back • Forecasters randomly assigned radar for first case run-through • Switched radar for second run-through
Wednesday afternoon	Supercell	• Two similar cases worked back-to-back • Forecasters randomly assigned radar for first case run-through • Switched radar for second run-through
Thursday morning	QLCS	• Forecasters worked with PAR in two-person teams • One was warning forecaster • One was DSS forecaster communicating threat info via Slack
Thursday afternoon	QLCS	• Exact same case worked back-to-back. • Forecasters randomly assigned radar for first case run-through • Switched radar for second run-through

Table 1. Basic information about the cases forecasters worked during each HWT week[1].

3.2 Surveys and Focus Groups

Scientists within the Social Science Research Team and Precipitation and Advanced Radar Studies Team at NSSL/CIWRO followed well-established, social-

[1] Additional case details available upon request.

science driven survey development best practices when designing survey instruments[2]. After developing the surveys, each one was piloted by former NWS forecasters or other members of the Social Science Research Team to ensure question clarity and proper survey flow. During the August 2024 HWT activity, each end-of-case survey focused on a specific aspect of PAR data (e.g., update time). While this approach allowed forecasters to focus their feedback on a given radar data aspect, it limited researchers' ability to gather survey responses for all aspects of PAR data across all case types. Therefore, we changed our approach during the February 2025 HWT activity and asked questions about all aspects of PAR data in every end-of-case survey. We also modified and added some questions to the February 2025 end-of-week survey to better answer our primary research questions based on what we learned during the August 2024 HWT activity.

Each focus group discussion typically lasted between 30–60 min and centered around the advantages and disadvantages of the radar data forecasters worked with during each case, especially in terms of how it impacted their warning confidence and ability to identify storm-scale processes. As time allowed, we also asked questions about the ideal radar scan update time for each case type, data visualization techniques, radar scanning strategy design, and the screenshots forecasters took during the case. The end-of-week focus group on Friday morning lasted about two hours and drew from the forecasters' overall experience throughout the week. Questions focused on a wide variety of topics, including the impacts of radar data on understanding and decision making, scanning strategy design, potential algorithm use with PAR data, workload and workflow when using PAR data, data visualization, training, and recommendations for future HWT activities.

We analyzed the qualitative data from the open-ended survey questions and focus group discussions using two different approaches. Three of the open-ended survey questions were asked on every end-of-case survey in August 2024 and February 2025, which resulted in a large number of responses (n = 280–299) for these questions. For these responses, we performed a content analysis (e.g., Vaismoradi et al. 2013), where researchers assigned each response to one or more codes (i.e., themes). The researchers involved in the analysis first coded 10% of the August 2024 responses and met to ensure that the agreement between them exceeded 80%. Each researcher then coded a portion of the remaining survey responses. The same researchers then coded the February 2025 responses since the questions asked and codes remained the same. The frequency of each code was then determined and common themes were created. The remaining open-ended survey questions had much smaller sample sizes because they were only asked during 1–2 surveys. Due to this sample size limitation, researchers

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[2] Partial survey instruments (i.e., documents containing survey questions) in Appendix 1 and full instruments available upon request.

read through these responses multiple times and identified any common themes for each question.

4. HWT Activity Results

During both HWT activities, forecasters overwhelmingly preferred working with PAR data over WSR-88D data. During the February 2025 HWT activity end-of-case surveys *only*, we specifically asked forecasters which radar they preferred working with for each case type, and a vast majority chose PAR (Fig. 2). Across the August 2024 and February 2025 surveys and focus group discussions, this PAR preference was especially pronounced for cases with tornadic thunderstorms because the faster update times and increased vertical coverage better captured the evolution of key storm-scale processes such as rear-flank downdrafts, descending rear-inflow jets, and tightening low-level rotation. It is therefore not surprising that forecasters most strongly agreed that faster updates and increased vertical coverage were preferred aspects of PAR data over WSR-88D data (Fig. 3).

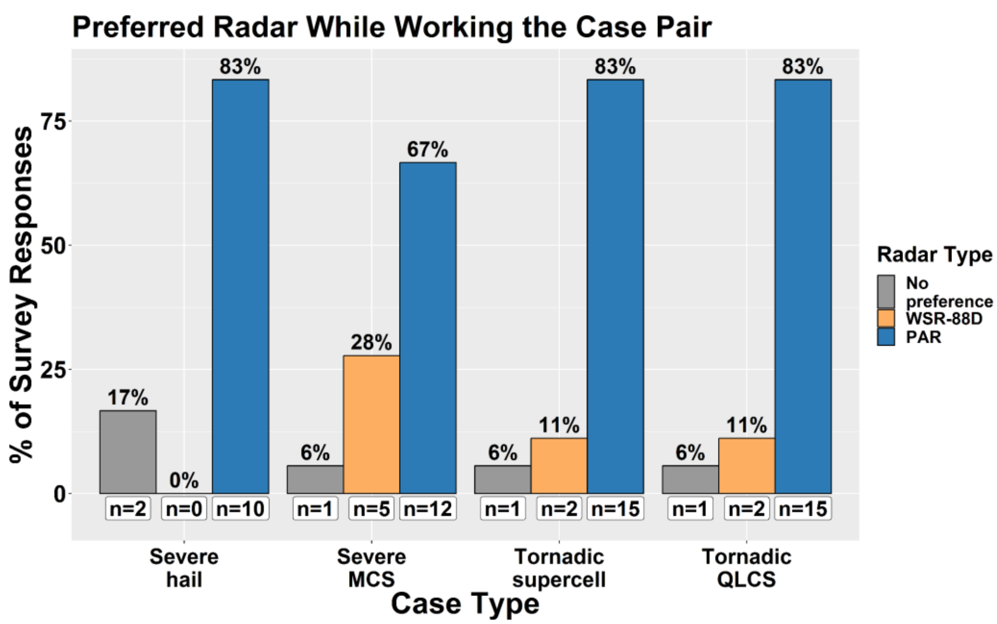

Figure 2. Percent of February 2025 end-of-case survey responses who preferred working with PAR (blue bars), WSR-88D (orange bars), or no preference (grey bars) for the storm mode case pairs they worked.

The PAR preference emerged despite the limitations of the proof-of-concept KATD data (i.e., not representative of a future operational radar network) they worked with during the week. Forecasters in the HWT certainly noted these limitations and that the associated challenges can reduce the benefits of faster scanning times, but it tended to not overwhelm those benefits (section 4.1–4.5). Even the dual-pol data clarity and velocity data of the KATD were preferred by forecasters despite those aspects being most impacted by the beamwidth, sensitivity, and noisiness limitations (Fig. 3). This finding is notable since it is very likely that the data provided by a future operational network of PARs will have better overall quality than what the forecasters worked with in the HWT. Some of the potential reasons for these forecaster preferences are outlined in the following subsections.

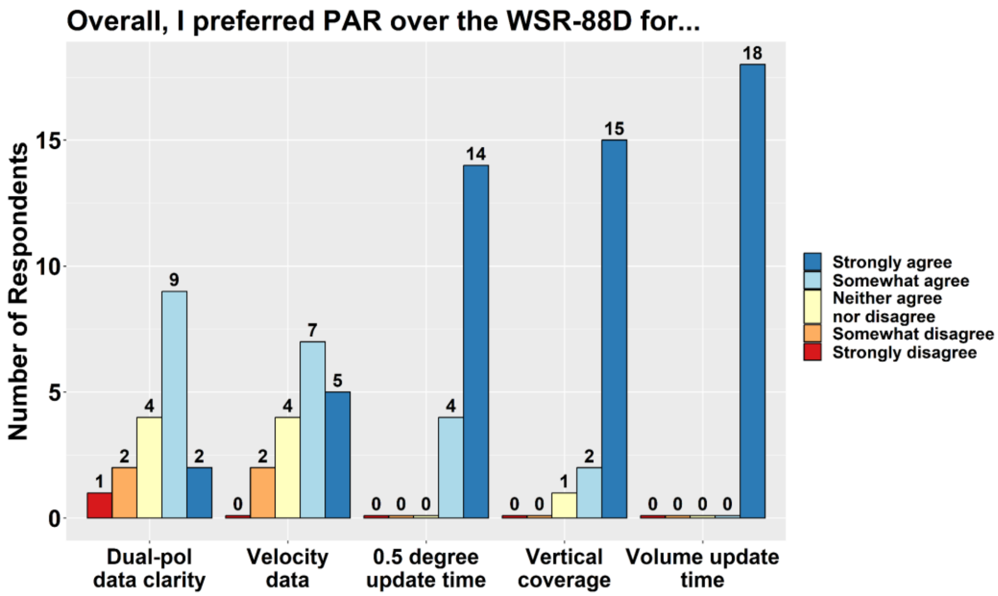

Figure 3. February 2025 end-of-week survey responses indicating forecaster agreement regarding preferring various aspects of PAR data over WSR-88D data.

4.1 PAR Data Impacts on Identifying Storm-Scale Processes

After select cases during the August 2024 HWT activity and after every case during the February 2025 HWT activity, we asked forecasters how much they agreed or disagreed that the volume update time, vertical coverage, and dual-pol data clarity of the radar data they just worked with was sufficient to easily identify storm-scale processes. The largest differences in agreement between PAR and WSR-88D occurred with the volume update time. For PAR, 95% of survey responses either strongly or somewhat agreed that the volume update time was sufficient, while for the WSR-88D, only 44% of responses either strongly or somewhat agreed and 35% either strongly or somewhat disagreed (Fig. 4a). On a scale from one to five, with one being strongly disagree and five being strongly agree, the mean agreement was 4.71 for PAR and 3.11 for WSR-88D and the difference in the distributions was statistically significant at the 99% confidence level, according to the Kolmogorov-Smirnov (KS) Test[3]. For vertical coverage, the mean

[3] The KS test is a non-parametric method to determine the degree of difference in the distributions of two data sets.

agreement was 4.84 for PAR and 4.18 for WSR-88D, with 99% and 87% of responses indicating that PAR and WSR-88D data were sufficient, respectively. The distributions between PAR and WSR-88D were more similar than for update time, but the differences were still significant (Fig. 4b). For dual-pol data clarity, the mean agreement was 4.36 for PAR and 4.06 for WSR-88D and the difference in the distributions was not significant (Fig. 4c).

These closed-ended survey responses align well with what forecasters said in the open-ended survey questions and the focus group discussions. Mentions of the usefulness of rapid update times occurred about six times more often than mentions of increased vertical coverage, and rapid update times were nearly always mentioned first during focus group discussions when asked about the advantages of the PAR data. Forecasters noted that rapid updates were helpful in seeing changes in storm intensity earlier and more easily, making decisions quicker and more confidently, tracking fast-moving storms, and communicating DSS information during the Thursday morning case (Table 2). When forecasters discussed increased vertical coverage, they often mentioned that it improved their ability to see vertical continuity in important radar signatures, such as reflectivity cores, descending rear-inflow jets, and storm-top divergence. Forecasters also felt that closely spaced elevation angles also improved the quality and usefulness of vertical cross sections and 3D volume displays in GR2Analyst (Table 2).

Regarding dual-pol data clarity and overall velocity data quality, forecasters tended to mention challenges during the open-ended survey questions and focus group discussions. Noise in the dual-pol data as well as dealiasing and censoring in the velocity data was frequently mentioned as one of the biggest challenges of the KATD data. However, despite these comments, forecasters still generally preferred the dual-pol and velocity data of the KATD over the WSR-88D (Fig. 3). This preference may relate to the issues having relatively minimal impact to their warning decision process or the benefits of the more rapid updates outweighing any negatives of the data issues (Table 2).

Objectively, KATD velocity data can have more noise, dealiasing errors, and data censoring compared to WSR-88D data due to experimental velocity dealiasing techniques. These issues are actively being addressed and improved such that the velocity dealiasing errors were reduced between the August 2024 and February 2025 HWT activities using similar methods as Alford et al. (2022). In addition, velocity data shown during both HWT activities is still likely lower quality than what the KATD can actually provide, especially in terms of data censoring in velocity couplets (Fig. 5). Forecaster comments about dual-pol data noise are interesting because, in general, there is statistically less variance in the KATD dual-pol data than the WSR-88D data due to a technique called range averaging (e.g., Curtis and Torres 2011; Alford et al. 2025). It is possible that forecaster comments regarding dual-pol data noise are related to the wider beamwidth of KATD compared to the WSR-88D (section 4.5).

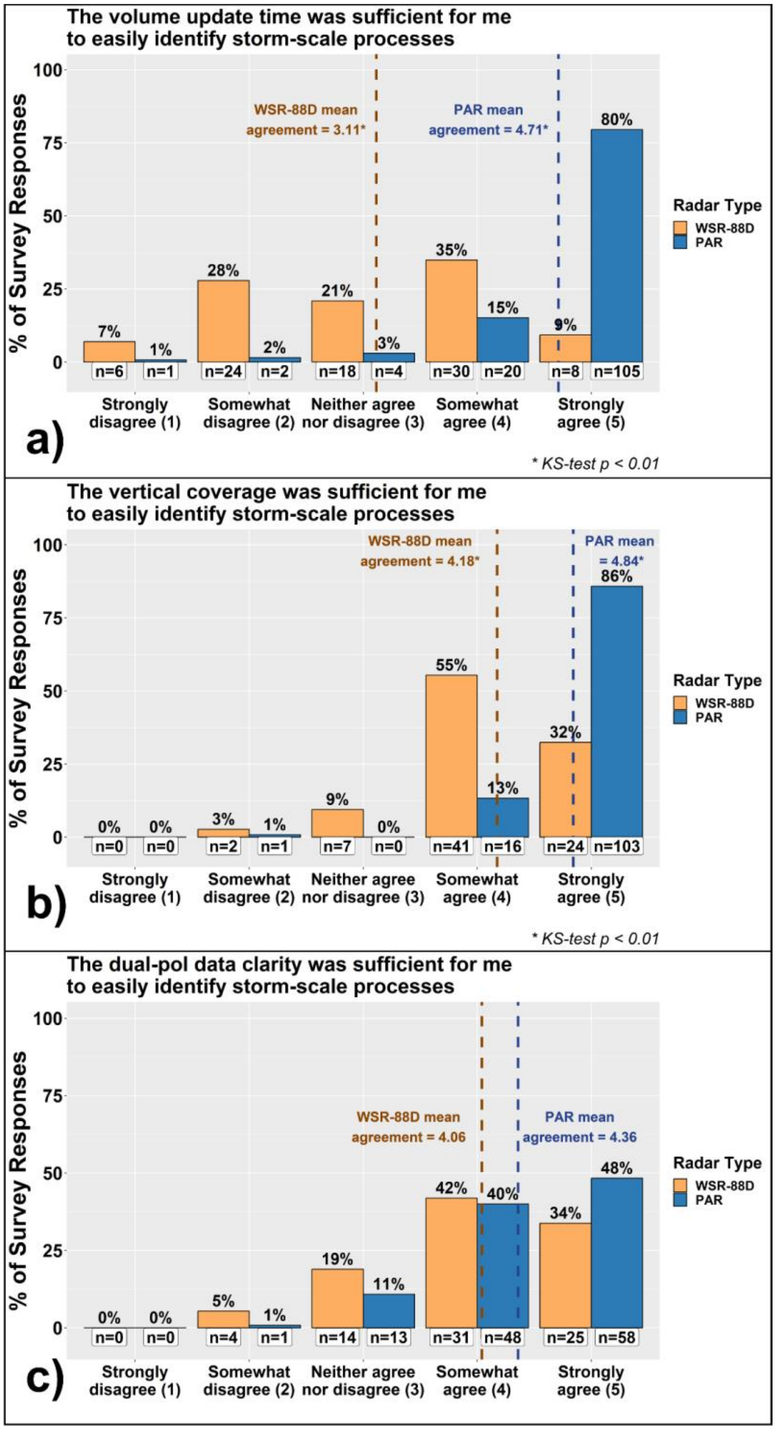

*Figure 4. Percent of August 2024 and February 2025 end-of-case survey responses showing forecaster agreement regarding the a) volume update time, b) vertical coverage, and c) dual-pol data clarity being sufficient to easily identify storm scale processes when using PAR (blue bars) and WSR-88D data (orange bars). Vertical dashed lines indicate the mean agreement for each radar and the * in a) and b) indicates that the distributions were statistically significantly different.*

Rapid Update Times
“I was less afraid to miss something during this event thanks to the quick update times which helped me have a better understanding of how storms were evolving. Key radar signatures which I frequently look for in tornadogenesis were much clearer to me using the [K]ATD data compared to what I would expect from an 88D, mainly because of the quicker update times.”
“The frequent updates at all levels of the [K]ATD were immensely helpful into determining the MCS intensity and strength of the winds, and allowed me to provide frequent warning updates.”
“Having more data available made warning operations feel more fluid as I had a better understanding of what was occurring. Interrogating the descending RIJ and K_{DP} cores is less difficult using the [K]ATD as long as the dual-pol data is good.”
Vertical Coverage
“Secondly the vertical resolution was noticeably better with the KATD radar due to the scanning strategies in use. You were able to get data within 500–1,000 ft of the freezing level,… which when combined with the much higher temporal resolution, gave you a fantastic volumetric display in GR and allowed you to see the fluctuations in elevated reflectivity cores.”
“[The] Increase [in] vertical resolution (more elevation scans) [was useful]. This makes GR2 cross-sections more usable, and overall allows you to see vertical continuity easier.”
Velocity Data Challenges
“The biggest challenges with the [K]ATD data were the dealiasing problems out ahead of the main line, which I could mentally filter out but was distracting.”
“At the same time, data quality issues with the [K]ATD velocity couplets gave me lower confidence in tornadoes occurring versus the 88D data.”

Table 2. Forecaster quotes regarding PAR (KATD) update times, vertical coverage, and velocity data challenges and how they impact understanding of storm-scale processes. Text in [ ] was added by researchers for clarity.

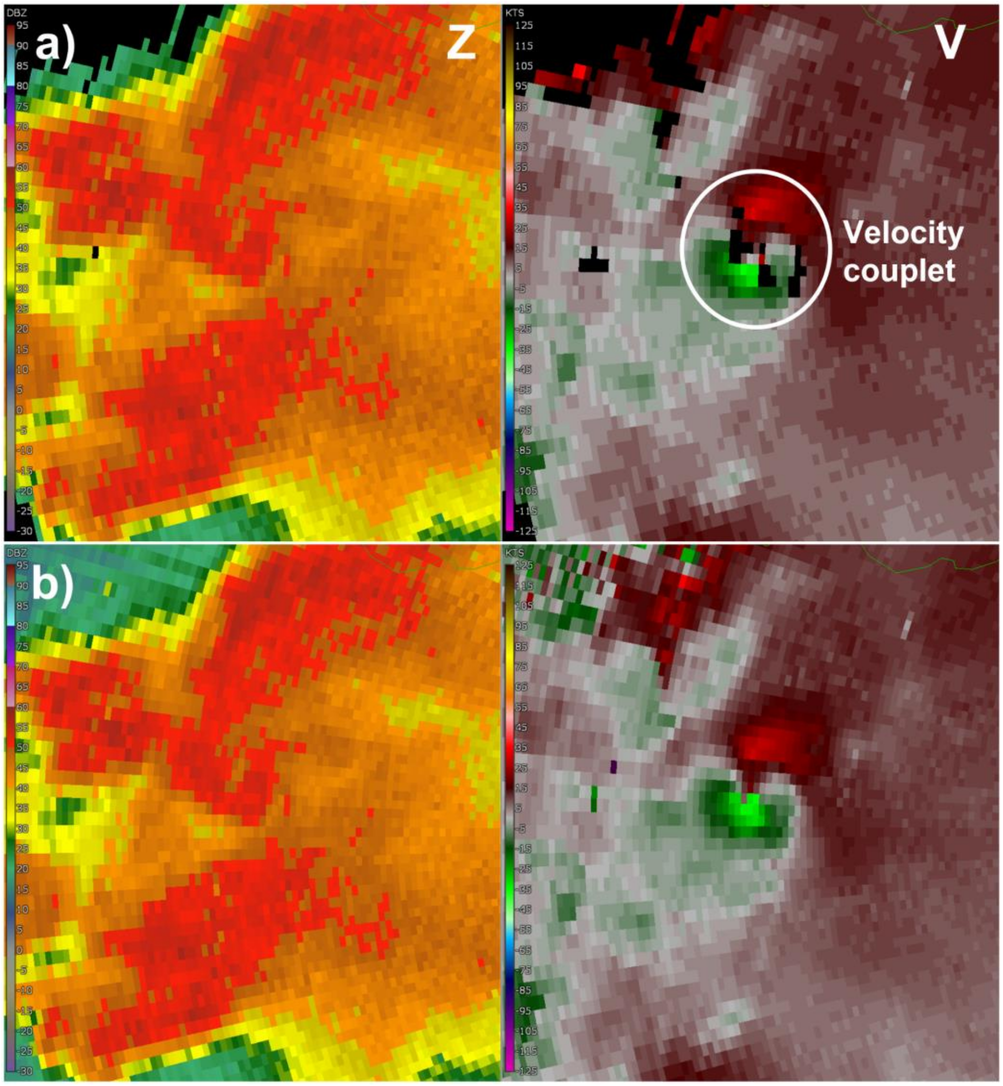

Figure 5. KATD 0.9° tilt reflectivity (left) and velocity (right) showing a) data used by forecasters in the HWT with increased velocity data censoring (black pixels) within the velocity couplet (white circle), and b) data with reduced velocity data censoring.

4.2 PAR Data Impacts on Warning Confidence

Similarly to identifying storm-scale processes (section 4.1) forecasters agreed significantly more that PAR's volume update times and vertical coverage were sufficient to be confident in the warnings they issued than the WSR-88D's (Fig 6). Despite these responses, when asked to rate their overall warning confidence, both PAR and WSR-88D had similar ratings. Across all end-of-case surveys in August 2024 and February 2025, the mean reported warning confidence was 4.08 for PAR and 3.75 for the WSR-88D (Fig. 7a). However, more survey responses selected "extremely confident" for PAR than the WSR-88D and more selected "somewhat confident" for the

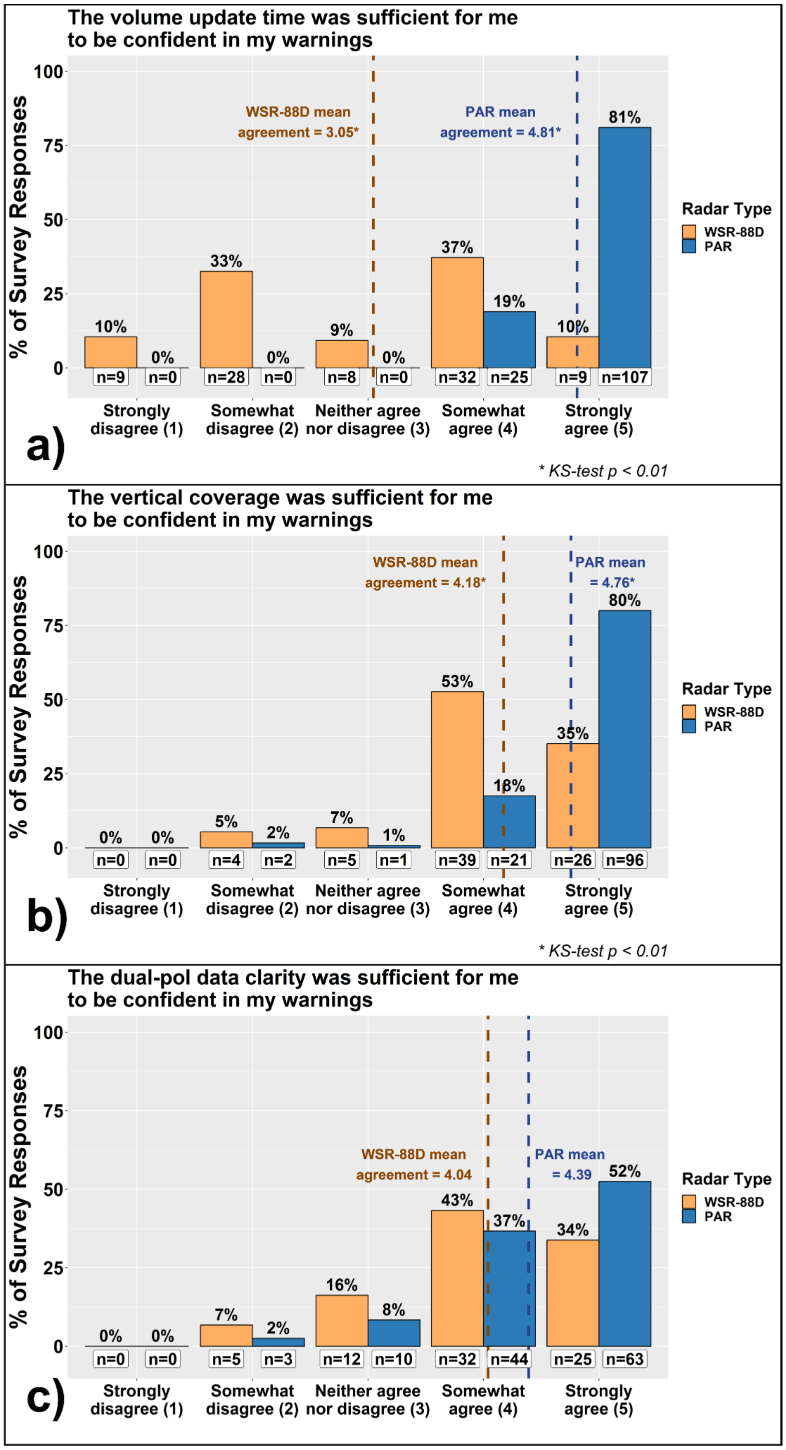

*Figure 6. Percent of August 2024 and February 2025 end-of-case survey responses showing forecaster agreement regarding the a) volume update time, b) vertical coverage, and c) dual-pol data clarity being sufficient to be confident in the warnings issued when using PAR (blue bars) and WSR-88D data (orange bars). Vertical dashed lines indicate the mean agreement for each radar and the * in a) and b) indicates that the distributions were statistically significantly different.*

WSR-88D than PAR (Fig. 7a). This imbalance suggests that forecasters feel somewhat more confident in the warnings they issue while working with PAR than the WSR-88D despite the mean confidence levels being similar. This idea is also evident when looking at warning confidence for each storm mode individually (Fig. 7b). Mean confidence is slightly higher, but not significant, for PAR than the WSR-88D for the large hail, mesoscale convective system (MCS), and quasi-linear convective system (QLCS) cases and is significantly higher for PAR in the tornadic supercell cases. The most significant differences between PAR and WSR-88D also occurred with tornadic supercells in terms of overall radar usefulness (Fig. 7c) and radar update time being sufficient to be confident in issued warnings (Fig. 7d). These results suggest that forecasters see the largest potential benefits of PAR data in events with tornadic supercells, at least for those that produce weaker tornadoes as that is what they encountered in the HWT. This idea could be important because supercell tornadoes account for about 95% of tornado-related fatalities in the United States (e.g., Anderson-Frey and Brooks 2019).

While the close-ended survey questions indicated similar warning confidence between both radar systems, in the open-ended survey questions and focus group discussions, forecasters frequently reported having higher warning confidence when using PAR. This higher confidence arose due to PAR's faster update times and increased vertical coverage depicting important radar signatures earlier and more clearly, capturing a more complete picture of storm evolution, and filling in the pieces of their conceptual models (Table 3). They also noted that while using WSR-88D data, they had to infer what was going on in between volume scans, whereas while using PAR data, they could actually observe the processes without having to mentally fill in the gaps. One forecaster summed this idea up well by explaining that more observing and less inferring allowed them to think more critically about the storm-scale processes rather than simply reacting to one volume scan as they might have to do with WSR-88D data. The quantitative and qualitative data suggest that while forecasters feel confident in their warnings when using either PAR or WSR-88D data, overall they feel better about the warnings they issue when using PAR data because the rapid-update times allow them to visualize storm evolution and intensity more clearly (Table 3).

Further context from the open-ended survey questions and discussions suggests that radar data is not the only factor that influences warning confidence. The most common response to the overall warning confidence question related to the challenges or advantages posed by certain storm hazards and environments. For example, downburst events and marginal environments tended to decrease overall warning confidence. Second, forecasters mentioned having confidence in warning decisions while using either PAR or WSR-88D—despite the challenges each one presented—and this idea aligns well with the mean confidence being nearly "very confident" for both PAR and the WSR-88D in the closed-ended survey questions (Fig. 6, Table 3). High warning confidence while using the WSR-88D also makes sense as it is the radar system that forecasters train on and use in everyday operations. The fact that forecasters reported slightly higher confidence when working with PAR is therefore noteworthy and likely points to the positive impact of faster update times and increased vertical coverage on the warning decision process.

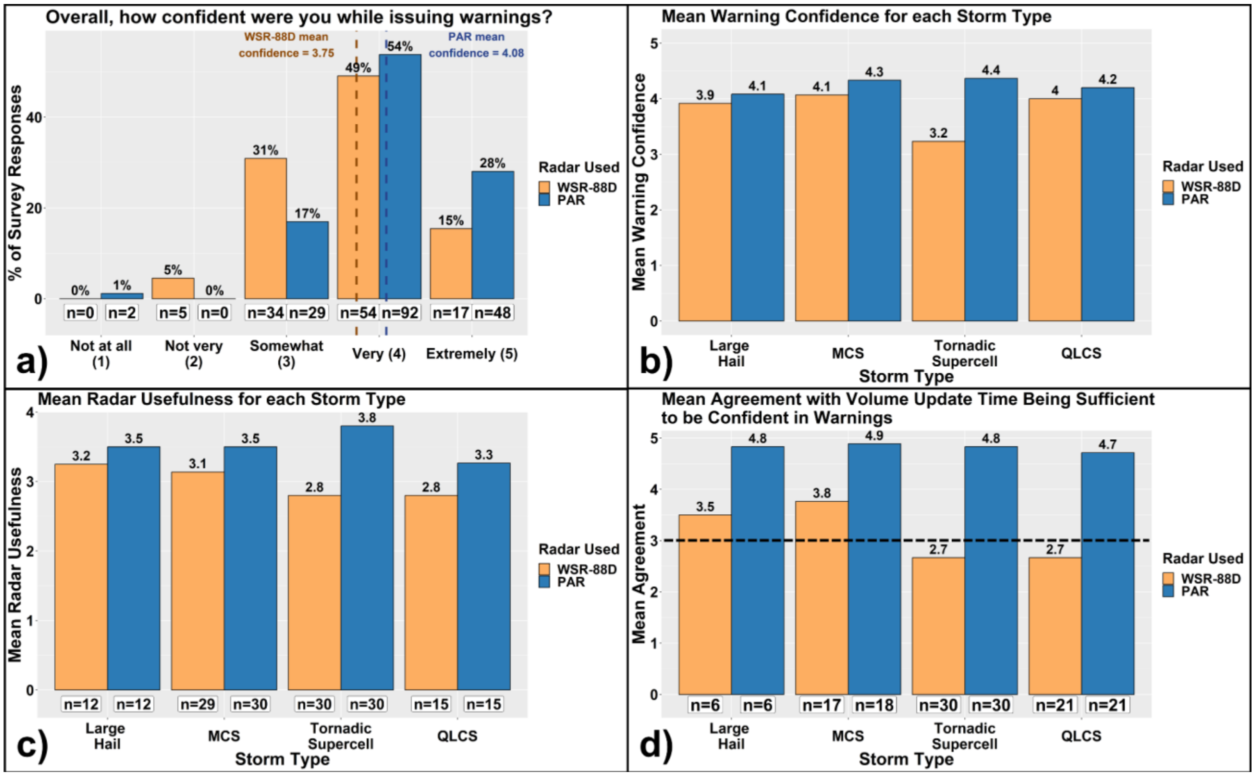

Figure 7. End-of-case survey responses for August 2024 and February 2025 showing a) forecaster warning confidence across all cases, b) mean warning confidence across different storm types, c) mean radar usefulness rating across different storm types, and d) mean agreement that volume update time was sufficient to be confident in issued warnings when using PAR (blue bars) and WSR-88D data (orange bars). In a), vertical dashed lines indicate the mean agreement for each radar. In b), confidence values on the y axis are: not at all (1), not very (2), somewhat (3), very (4), and extremely (5). In c), usefulness values on the y axis are: not very (1), somewhat (2), very (3), and extremely (4). In d), agreement values on the y axis are: strongly disagree (1), somewhat disagree (2), neither agree nor disagree (3, marked with horizontal dashed line), somewhat agree (4), and strongly agree (5).

Rapid Updates and Denser Vertical Coverage Increased Confidence
“The biggest factor [for increased warning confidence] is watching a process, and seeing the evolution of signatures…With the 88D, you may be able to catch one scan or two of it, but then it is gone. Here, I was able to apply basic supercell, QLCS, and multi-cell concepts when analyzing the data. I spent less time reacting, and more time anticipating.”
“[Biggest benefit of PAR was] less time reacting to scans, more time anticipating processes. We all have meteorology backgrounds, and the rapid number of scans allows us to critically think about our knowledge. The PAR pulls more out of the meteorologist.”
“If we add more data to fill in those gaps that we're mentally putting data into right now, we are taking a lot of the uncertainty out of the warning decision process. And so I think what you're going to end up seeing is not more uncertainty. You're going to be able to be more decisive in your warning decisions.”
“[Issuing QLCS tornado warnings] definitely felt more comfortable using the [K]ATD data compared to slower 88D data. The quicker update times/more elevation scans made me more confident to issue tornado warnings and it was easier to identify developing mesovortices.”
Confident With Both Radars, But Better with PAR
“I felt I was still able to perform my radar duties well and was confident in my decisions made [using 88D data]. However the lower temporal resolution of the 88D made me feel like I was missing out on potential lead time in a decision as I was waiting for new scans to arrive.”
“1-min PAR data compared to 5-min 88D data revealed a lot more about the ongoing situation. Understanding the storm-scale processes with more clarity resulted in higher confidence warnings. It doesn't mean the job doesn't get done with 88D data, but I think PAR data help clear up some of the hesitancy or nervousness [with] issuing warnings.”
“While the 88D data were sufficient to make warning decisions, I definitely noticed gaps in temporal and vertical coverage which made me much less aware of the rapidly evolving storm-scale processes that occur during an event like this [a tornadic QLCS].”

Table 3. Forecaster quotes regarding the impacts of radar data on warning confidence. Text in [ ] was added by researchers for clarity.

4.3 PAR Data Impacts on Forecaster Workflow and Data Use

Forecasters noted both benefits and challenges for PAR data in terms of how they interact with and interrogate radar data. When asked a question about the biggest challenges of using PAR data, forecasters often noted that keeping up with PAR's rapid updates was one of them. Some responses mentioned the challenges of managing more data and feeling overloaded, that having to look through more data increased fatigue, and the challenge of continuing to monitor and interrogate rapid-updates even while they were drawing up a warning in WarnGen (Table 4). However, it is important to note that there were substantially more mentions of the slow update times of the WSR-88D being a challenge than the fast update times of PAR (45 vs. 28 respectively). Some forecasters even found that PAR data decreased their mental workload and fatigue (Table 4) and nearly all forecasters became more comfortable with the PAR data as the HWT week progressed (Fig. 8). This increase in comfort likely occurred as forecasters adapted their typical workflow to better accommodate the cadence of PAR data and became more familiar with how the signatures they typically look at in WSR-88D data appear in PAR data (Table 4).

PAR, if implemented in an operational environment, would likely require changes in forecaster data workflow as well as new data visualization techniques and algorithms. Some adaptation strategies forecasters mentioned were:

1. Not looking at every single elevation angle that came in but instead focusing on the most important data for the given storm hazard. Forecasters acknowledged that data they may not look at could still be useful for algorithms and was therefore still important.
2. Looping the data, especially in GR2Analyst, to better look for important trends.
3. Taking advantage of the vertical cross section and volumetric displays in GR2Analyst to quickly visualize the full volume of PAR data.
4. Adjusting AWIPS procedures to better handle PAR data and how it comes in. For example, one forecaster mentioned shifting from using an all tilts display to a 9–12 panel display showing multiple elevation angles at once.

Several forecasters also noted an interesting shift in their workflow from evaluating single scans with the WSR-88D to evaluating and anticipating storm-scale processes with PAR. Similarly to this idea, some forecasters also noted that their workloads were shifted due to the differences in volume update time. With PAR, the understanding and decision making happens up front quickly (i.e., "front-loaded") and then there is more time to monitor storm evolution and intensity (Table 4). One forecaster likened this process to running intervals versus running a marathon. With PAR, fast evaluations (a sprint) of rapidly incoming data allowed for workflow and warning decisions to progress very quickly in a short period of time followed by a lull (a cool down). With the WSR-88D

Challenges Managing PAR Rapid Updates
“However, getting quicker update times meant I had to keep my eyes on the radar at all times since everything was rapidly evolving so this would likely tire me out quicker on radar than when using an 88D for warning operations.”
“For me, there was a fear of “missing something” in the KATD data, so I felt I needed to work faster with less “downtime” when using the [K]ATD data. This improved as the week went on.”
Challenges with WSR-88D Slower Update Times
“Update times were on the order of 6 min aloft which made it difficult to understand how quickly the storms were organizing and when a warning should be issued.”
Adapting to PAR Data
“I feel like at the start of the week, I was actively trying to look at all levels and all the data. As the week went on I felt I focused in on what helped me the most. So overall, later in the week, I felt less overwhelmed with the amount of data coming in to interpret.”
“At the start of the week, I had trouble using this 12-panel plot with [K]ATD, but I later redesigned [it] to work better once I had an understanding of how [K]ATD data came in.”
“When using KATD data, I found myself gravitating towards the lowest few slices in AWIPS and relying more on volumetric data in GR.”
Changes in Data Workflow
“I discovered that my workload distribution changed with PAR: warning decisions were made quickly, confidently and front-loaded, which left me more time to sit back and watch things evolve and be ready to change course as needed.”
“So I actually think I was less fatigued, less burnt out, and had less workload with the more frequent updates. …instead of every six minutes getting a volume scan and feeling like now I have a checklist of five things to do, suddenly. I was able to do those five things over six minutes with the [K]ATD data, so it was a little bit easier, more bite sized decision making, one step at a time versus every full volume scan…”
“I also found I was spending less time analyzing “the latest scan”, and rather, I was looping through a process with the frequent updates of the [K]ATD. I think this helped my analysis because I wasn't a sitting duck on just one scan waiting for the next one to come in. I [was] always thinking about storm morphology and evolution. This is [a] major, beneficial change to my warning work flow.”

Table 4. Forecaster quotes regarding challenges encountered with PAR and WSR-88D radar update times, how they adapted to PAR data during the week, and how PAR data resulted in changes in their data workflow. Text in [ ] was added by researchers for clarity.

data, the slower incoming data resulting in extended workflow and warning decisions over longer periods of time (a marathon). Several forecasters agreed that this idea explained why they felt less fatigued using PAR data compared to WSR-88D data. These concepts as well as the adaptation strategies likely explain why a large majority disagreed that PAR (i.e., KATD) volume update times were too fast and that the update times were overwhelming (Fig. 8).

Other interesting themes included an increased desire and need for high-quality algorithms to assist forecasters in data triage with the increased amount of data provided by PAR. Forecasters also mentioned a higher likelihood to become focused on a single storm or hazard since PAR data update quickly, which results in a lowering of situational awareness and the realization that they need to zoom out and interrogate other storms as well. In addition, forecasters noted that their perception of time was different with PAR in that they are accustomed to the slower WSR-88D volume update times and applied that mindset to PAR's rapid volume updates. This mental conceptualization of time led forecasters to feel as though more minutes had passed than had actually elapsed because of the increased amount of data from PAR. Forecasters also mentioned uncertainty about what constituted a reliable trend in rapid-update data instead of short-lived, unimportant, temporary jumps in storm intensity. Much of this forecaster feedback suggests that many of the challenges forecasters reported when working with PAR would be alleviated with the creation of advanced and adaptable data visualization techniques, PAR-specific training, and algorithms that can alert forecasters to the most important or threatening storms to focus on within a 360-degree data sector.

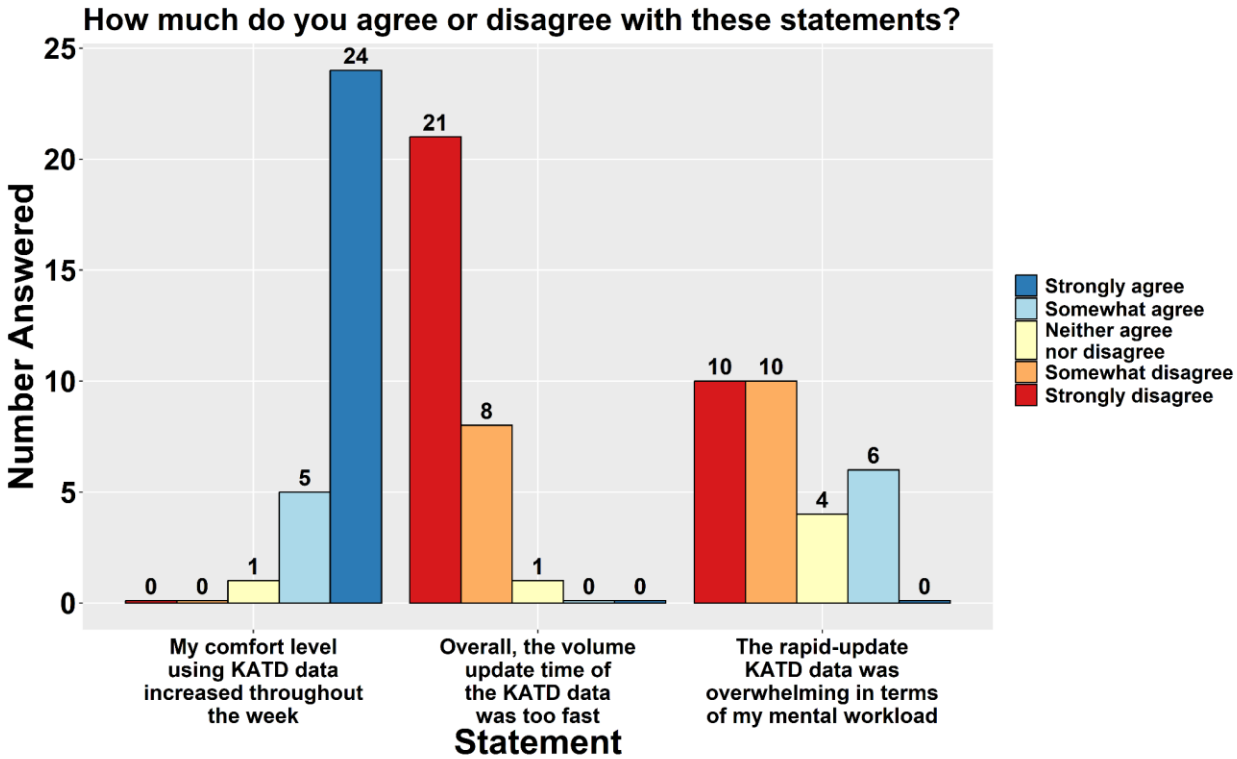

Figure 8. End-of-week survey responses for August 2024 and February 2025 showing forecaster agreement or disagreement with statements regarding PAR (KATD) data.

4.4 Potential Benefits of PAR Scanning Flexibility

While not a focus of our HWT activities, several survey and focus group questions revealed potential benefits of the scanning flexibility a PAR system could provide (e.g., Zrnić et al. 2007; Torres 2024). We asked forecasters about their ideal volume update time in the February 2025 end-of-week survey and in the August 2024 and February 2025 end-of-week focus groups. The survey responses were similar for all storm modes and for most forecasters, with the most common ideal update time being 1.0–1.5 min (Fig. 9a). However, during the focus groups, individual forecaster preferences in update times became more apparent. Some forecasters preferred slower volume update times while others preferred faster update times. In addition, the ideal update time and ideal scanning strategy differed for various storm modes. Forecasters mentioned observing the lowest 2–3 elevation angles of a supercell every ~30 sec to monitor the tornado threat while also maintaining a volume update time of 1–1.5 min to monitor the hail threat. For multicells only producing large hail, forecasters generally agreed that the whole storm could be scanned in the same way with a volume update time of 1.5–2.0 min, though some did mention scanning hail-growth regions more rapidly. Many forecasters also saw value in the ability to be flexible with scanning strategies, including the ability to use range height indicators (RHIs), customize volume coverage patterns (VCPs) for storm modes and geographic regions, adjust update times at different heights within a storm depending on the primary hazard, and focusing attention (e.g., increasing update time, vertical coverage, and data clarity) on the most important portions of a given storm (Table 5). It became clear over the six weeks of HWT activities that each forecaster is different. They have different preferences and different ways of interrogating storms. PARs could provide the flexibility to allow each forecaster to customize the radar scanning strategies closer to their liking and allow them to have the radar they need when and where they need it.

In the end-of-week surveys, we also asked forecasters what heights within a storm they look at most often for various hazard types. Unsurprisingly, these heights differed based on the hazard type. For example, forecasters tend to look at the lowest three elevation angles most frequently during tornado and wind events (Fig. 9b), but looked at an elevation angle near -20°C (i.e., upper levels) most frequently during hail events (Fig. 9c). Increased radar scanning flexibility would allow the most important heights within a given storm to be observed with more frequent updates, increased vertical coverage, and improved data clarity, which could increase forecaster confidence and understanding across the spectrum of storm modes and hazard types.

Potential Benefits of Flexible Scanning
"What [VCPs] may work in the Dakotas may not work in the lower Mississippi Valley. What's going to work in Western Region may not work in Eastern Region. [What VCP will work for] An HP supercell versus an LP supercell, [or a] dry microburst vs wet microburst. There's not just a set VCP that's going to work for all of those different storm types. But it's configurable [PAR VCPs]. So, you deliver it in the field. You get experts, radar meteorologists, and you determine what's going to work best for what kind of weather type you're forecasting. So that's the beauty of it."
"…the ability to incorporate an RHI, I think it's something that would be well-received, especially since it wouldn't impact your update times in terms of a full volume…"
"And the fact that you have so much more flexibility and customizability with the phased array radar opens up so many options for sampling storms based upon convective mode and the most likely storm hazards."
"Making a dynamic VCP where you can designate the heights you want the beam at would be I think the ideal world. "

Table 5. Forecaster quotes regarding increased scanning flexibility provided by PARs. Text in [ ] was added by researchers for clarity.

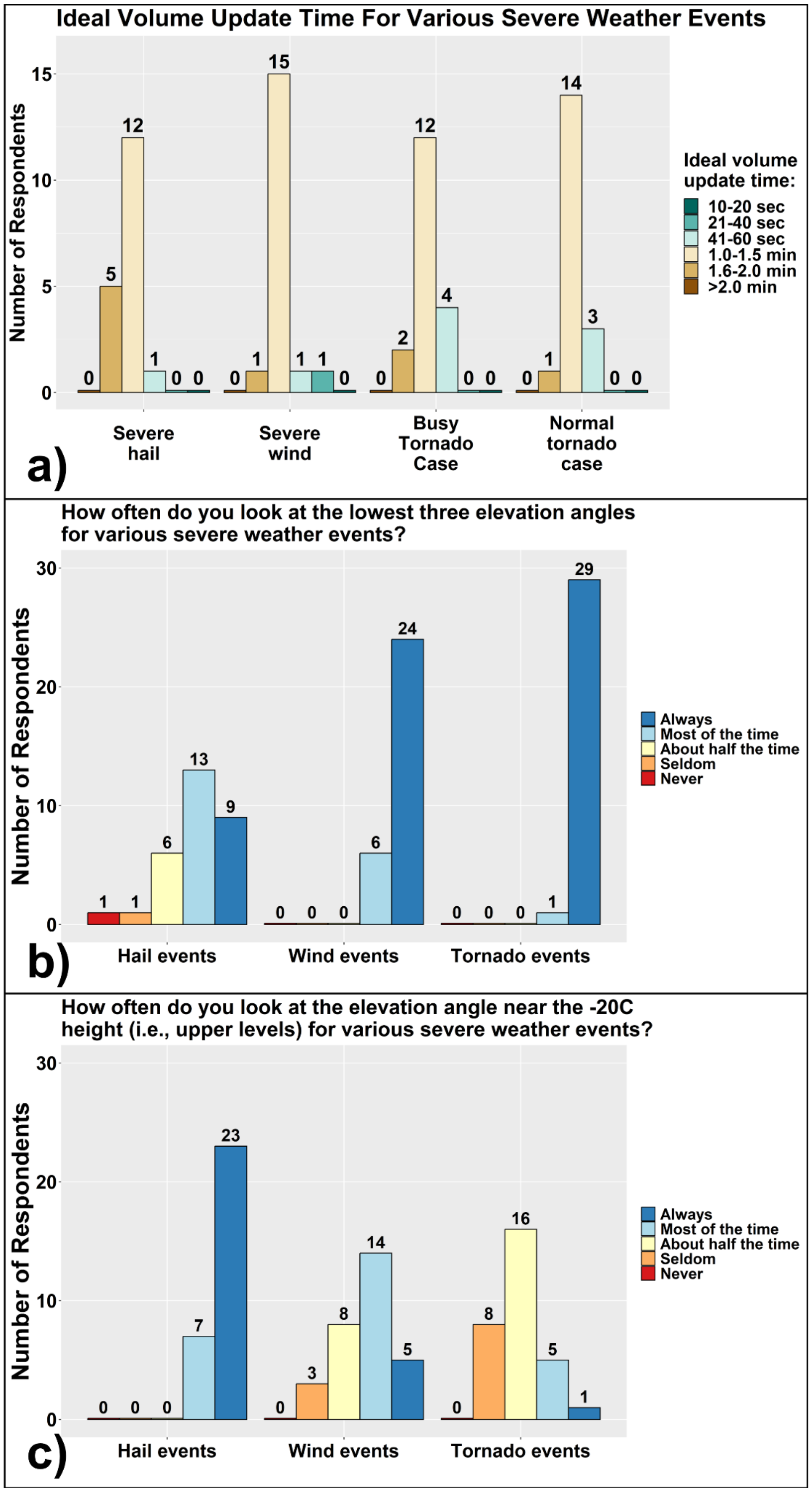

Figure 9. Results from a) February 2025 end-of-week surveys showing forecaster ideal update time for various severe weather events, b) August 2024 and February 2025 end-of-week surveys showing how often forecasters reported using data at the lowest three elevation angles for various severe weather events, and c) same as b) but for an elevation angle near the -20°C height.

4.5 Radar Beamwidth (i.e., Resolution) is Important to Forecasters

The KATD is a research radar and is not representative of a potential future operational PAR. One characteristic of KATD that is likely not representative is its beamwidth of 1.6° at boresight and 2.1° at the edges of the 90° field of view, both of which are wider than the 1.0° effective beamwidth of the WSR-88Ds. A wider beamwidth results in lower spatial resolution, so it is not surprising that HWT forecasters noticed this difference and frequently mentioned it as a challenge in working with the KATD data. Across the surveys and focus group discussions, the biggest challenge noted with the wider beamwidth was about interrogating velocity signatures, especially at ranges beyond 50 nm (92.6 km) from the radar. Forecasters described the velocity data as “chunky” or “smooth” (i.e., lacking detail), which made velocity signatures more difficult to decipher and resulted in lower warning confidence (Table 6). The wider beamwidth also likely caused forecasters to describe some of the dual-pol variables as noisy or of lower quality especially at farther ranges, regardless of the fact that the KATD leverages range averaging to reduce the data’s spatial variance. These challenges likely explain why nearly every forecaster agreed that a future operational PAR network needs a beamwidth of less than 1.6° during the focus group discussions. Some forecasters noted the rapid updates made up for the challenges posed by the wider beamwidth, while others mentioned the benefits of the rapid updates being limited by the wider beamwidth (Table 6). Despite these challenges, a majority of survey responses still rated the KATD beamwidth as acceptable during the August 2024 end-of-week survey (Fig. 10a) and especially the February 2025 end-of-case surveys (Fig. 10b). It is likely that a future operational PAR network with a narrow beamwidth could be a “gold mine” of information, as one forecaster described it.

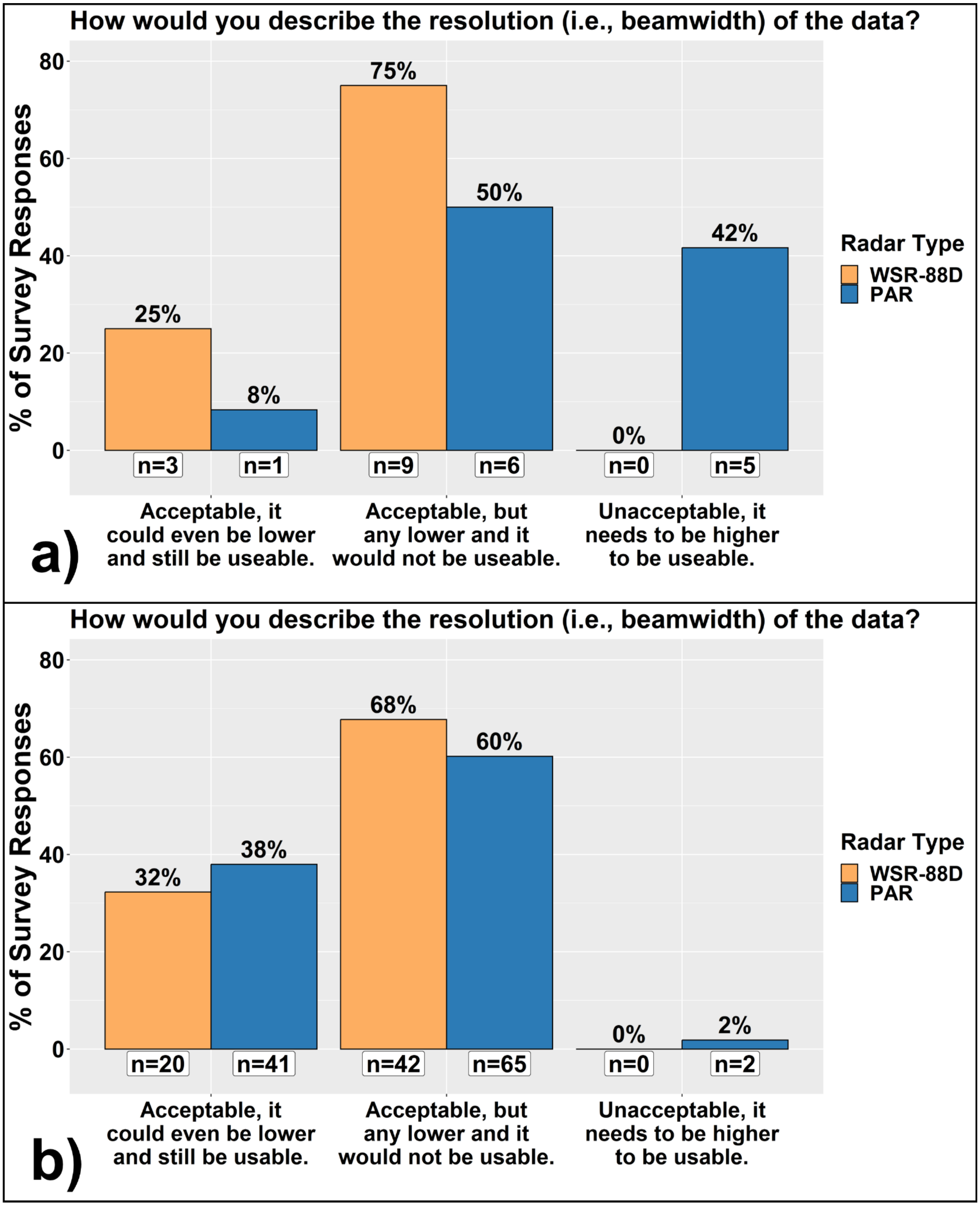

Figure 10. Percent of survey responses regarding the acceptableness of the resolution (i.e., beamwidth) of PAR (blue bars) and WSR-88D (orange bars) data for a) the August 2024 end-of-week survey and b) the February 2025 end-of-case surveys.

Impacts of Wider Beamwidth
“And the lower resolution and overall more “smooth” appearance of the velocity data made it harder for me to get a good feel for the mesovortices.”
“With distance from the radar and anything not in the center of the 90 [degree] sector some features were hard to see/define. Especially mesovortices/rotation. If we could get the beam width better I think this PAR data would be an absolute gold mine.”
“My confidence was increased by the update times, but decreased by the lower resolution of things like reflectivity and velocity. They didn’t totally cancel each other out but the confidence I could have gained from faster updates was inhibited by lower resolution.”
“The big takeaway is the faster volume updates and the more detailed volume vertical resolution. After these cases, I can trade off some of the spatial resolution for the greater temporal resolution.”

Table 6. Forecaster quotes regarding the impacts and challenges of the wider beamwidth, compared to the WSR-88D, of the KATD data they worked with in the HWT.

5. Quantifying Radar Signatures Observed by Forecasters During the HWT Activity

To provide additional context to what the forecasters saw and said during the HWT activities, we quantified the evolution of several important radar signatures noted by the forecasters. We quantified rotational velocity at various elevation angles for mesocyclones during the supercell cases and mesovortices during the QLCS case, as well as specific differential phase (K_{DP}) core magnitude at the elevation angle closest to but below the environmental melting layer for the downburst case (e.g., Kuster et al. 2021). To compare differing update times, we plotted rotational velocity and K_{DP} core magnitude of complete PAR data (i.e., every available volume scan) and degraded PAR data, where we removed volume scans to more closely match the update time provided by the nearest operational WSR-88D for that case (i.e., time-degraded PAR data).

As expected, what forecasters said about the radar signatures generally matched the quantitative, physical analysis. For example, forecasters expressed having higher confidence in anticipating tornado development during a supercell case when using PAR data because they could quickly see the magnitude of the rotation increasing rather than having to wait two or three minutes to see the increase. Indeed, the complete PAR data—with a 0.5° tilt update time of about 0.4 min—captured a rapid increase in mesocyclone rotational velocity about two minutes prior to the time-degraded PAR data and sampled the increasing trend seven times compared to one time by the time-degraded PAR data

(Fig. 11a). During a fast-moving tornadic QLCS case, forecasters noted that PAR's rapid updates on the lowest few elevation angles increased their tornado warning confidence because they could see short-lived trends in rotation more readily compared to the less frequent updates provided by the WSR-88D data. Indeed, the complete PAR data—with a volume update time of about 1.8 min—captured two short-lived periods of increasing and decreasing mesovortex rotational velocity that essentially occurred between the update times of the time-degraded PAR data (Fig. 11b). Lastly, during the downburst case, some forecasters said that they could readily observe the strengthening and subsequent descent of midlevel K_{DP} cores in the PAR data, which increased their confidence in strong winds occurring at the surface. Indeed, complete PAR data—with a volume update time of about 1.4 min—sampled an increasing trend in K_{DP} core magnitude about 3 minutes before the time-degraded PAR data and more completely sampled the full evolution of that K_{DP} core (Fig. 11c).

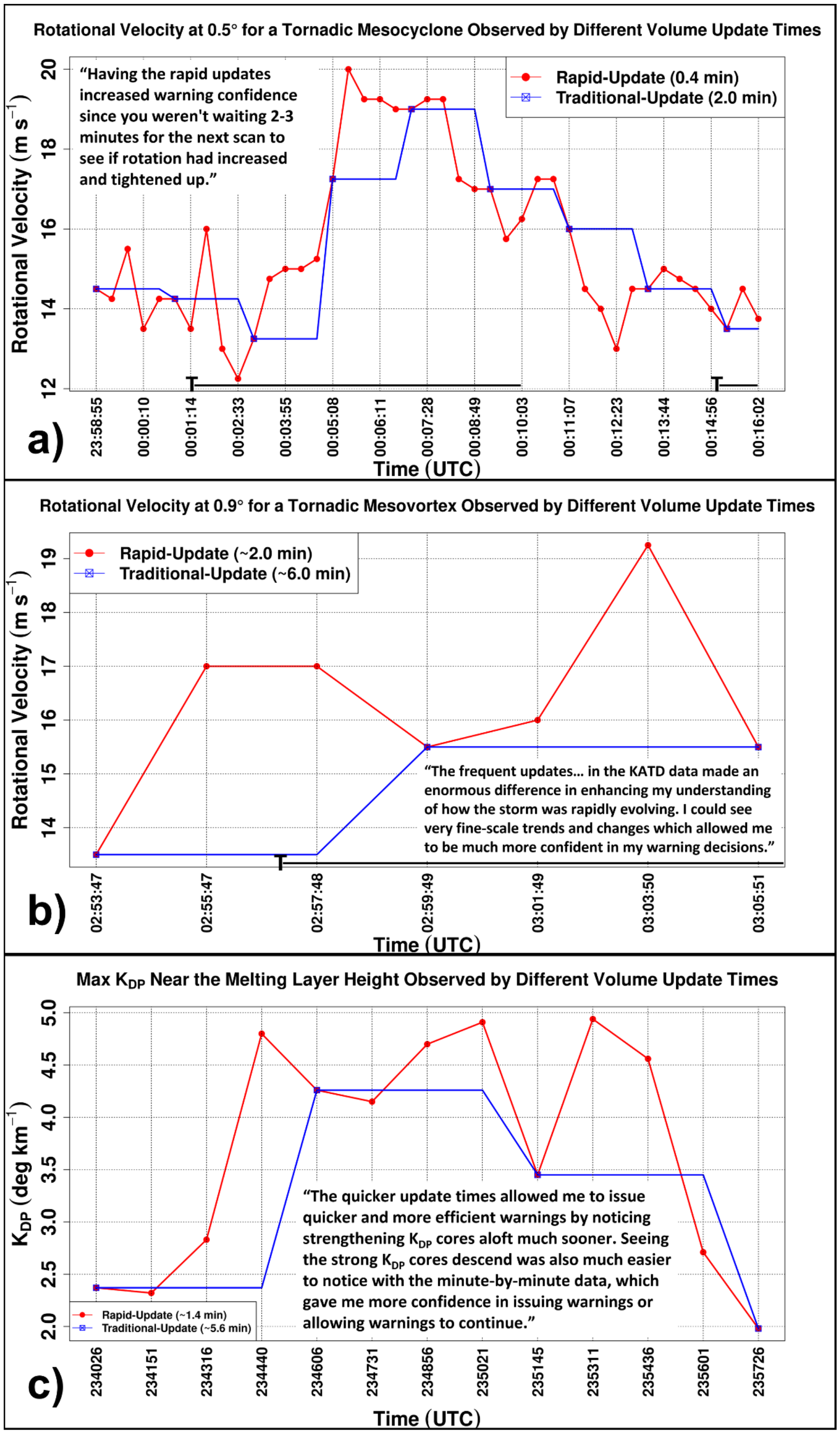

Figure 11. Time series showing evolution of a) 0.5° tilt rotational velocity in a supercell mesocyclone, b) 0.9° tilt rotational velocity in a QLCS mesovortex, and c) maximum midlevel K_{DP} core magnitude near the environmental melting layer height as sampled by full PAR data (red lines) and time-degraded PAR data (blue lines). ***T–*** *marks the time a tornado was reported to be ongoing in a) and b).*

6. Discussion

Through six weeks of interacting with NWS forecasters in the HWT, we have gathered large quantities of quantitative and qualitative data that provide insights into the potential impacts of dual-pol PAR data on forecaster understanding of storm-scale processes, warning confidence, and their thoughts about the benefits and challenges of using PAR in warning operations. Forecasters overwhelmingly pointed to the benefits of PAR, especially the rapid low-level and volume updates PAR can provide. In general, forecasters felt PAR was valuable because it allowed them to better understand storm-scale processes, improve their warning decision making and confidence, and ultimately provide a better warning service (Table 7). These results arise from the use of both single-pol and dual-pol data. Forecasters indicated using single-pol data more often than dual-pol data, but discussed several dual-pol radar signatures, such as tornado debris signatures, K_{DP} cores, and Z_{DR} arcs, that are used to better understand storm evolution and threats. These results are also consistent with those of previous PAR HWT studies (e.g., Heinselman et al. 2015; Wilson et al. 2017a) and an operational evaluation of the potential benefits of rapid-update satellite data conducted at the NWS Operations Proving Ground (Gravelle et al. 2016).

Forecasters also noted some challenges especially with the velocity data and beamwidth of the PAR data they used, and expressed that both should be improved. These challenges primarily deal with aspects of the research PAR system (KATD) used during the HWT that is likely not representative of a future operational PAR network. Beamwidth can be improved by using a larger antenna than the KATD and velocity data issues are already improving via additional research and refinement of algorithms (Fig. 5). Other challenges such as feelings of data overload and fatigue may be inherent with a PAR system, but they may also be a function of working with rapid-update data for the first time. Many forecasters reported becoming more comfortable with the PAR data by the end of the week and the feelings of data overload and fatigue were not universal among all HWT forecasters. These challenges can also be mitigated by new data visualization techniques, algorithms, and warning operations adjustments, such as ensuring there is a warning coordinator present to facilitate breaks, monitor forecaster fatigue, and rotate warning forecasters as needed. While not the only piece in selecting the next operational radar system, participating forecasters clearly believe that PAR is much more advantageous for their warning operations than a dish-based system, and their expertise is highly valuable.

Overall, Unifying Thoughts About PAR
"The PAR data made things pop out or stand out more and resulted in less time needed to look at each scan and interrogate it because the trends were much easier to establish."
"Like instead of getting itchy, [with PAR] we can just look at it and say, here's what's happening. We don't need to theorize or question what we're looking at and saying, do I need to make a decision now or should I wait another volume scan?"
"I feel it will be a game changer with its rapid update times, especially in QLCS tornado events. Looking at the 1 minute or less data allows you to see things you otherwise wouldn't be able to see and it almost felt like I was looking at a model [simulation] at times. We are now able to see things that we could only dream of before."
"I stopped reacting to scans [when using PAR], and I started thinking about the storm-scale process. And I love it because as degreed meteorologists, you're pulling out more value out of us because we're actually thinking about what we learned, rather than just trying to react to one data point. And so I think as meteorologists, we pull more out of the PAR and the PAR pulls more out of us."
"Having the ability to have what feels like instantaneous snapshots of a storm are very helpful to gain a few extra minutes in lead time in warnings."
"And then at the end of the day, if it just comes down to having an extra two minutes on that tornado warning because you had an extra two scans and you save a life, that's what it's all about. That's worth it."

Table 7. Forecaster quotes regarding overall thoughts about PAR and the impact it has on understanding and warning decision making. Text in [ ] was added by researchers for clarity.

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8. List of Acronyms

- HWT Hazardous Weather Testbed
- NOAA National Oceanic and Atmospheric Administration
- NSSL National Severe Storms Laboratory
- CIWRO Cooperative Institute for Severe and High-Impact Weather Research and Operations
- NWS National Weather Service
- WSR-88D Weather Surveillance Radar - 1988 Doppler (also 88D)
- PAR phased array radar
- KATD Advanced Technology Demonstrator
- QLCS quasi-linear convective system
- MCS mesoscale convective system
- VCP volume coverage pattern
- RHI range height indicator
- DSS decision support services
- Z reflectivity
- V velocity
- K_{DP} specific differential phase
- Z_{DR} differential reflectivity
- AWIPS Advanced Weather Interactive Processing System

- GR2Analyst Gibson Ridge Level 2 Analyst (radar viewing software)
- KS test Kolmogorov-Smirnov test
- HP high precipitation
- LP low precipitation
- RIJ rear-inflow jet

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Appendix 1: Selected Survey Questions from August 2024 and February 2025 HWT Activities

Table 8. List of selected survey questions that were referenced in this report.

End-of-case surveys
Which radar did you prefer using for these cases? [RANDOM ORDER] 0 - KTLX 1 - KATD 2 - No preference Please briefly explain your answer to the previous question. [OPEN RESPONSE]
Please briefly explain the biggest challenges you encountered while working this case? These challenges could relate to storm mode, unexpected storm behavior, radar data issues, missing an important dataset, etc. [OPEN RESPONSE]
Please rate how much you agree or disagree with the following statements based on your experience working this case. [MATRIX TABLE; Strongly disagree; Somewhat disagree; Neither agree nor disagree; Somewhat agree; Strongly agree; RANDOM ORDER] 1- The volumetric update time of the radar data was sufficient for me to easily identify storm-scale processes. 2 - The volumetric update time of the radar data was sufficient for me to be confident in the warnings I issued. 3 - The 0.5-degree elevation angle update time of the radar data was sufficient for me to easily identify storm-scale processes. 4 - The 0.5-degree elevation angle update time of the radar data was sufficient for me to be confident in the warnings I issued. 5 - I would prefer faster volume update times compared to what I saw during this case. 6 - I would prefer faster 0.5-degree elevation angle data (i.e., more SAILS tilts) compared to what I saw during this case.
Please rate how much you agree or disagree with the following statements based on your experience working this case. [MATRIX TABLE; Strongly disagree; Somewhat disagree; Neither agree nor disagree; Somewhat agree; Strongly agree; RANDOM ORDER]

1 - The vertical coverage of the radar data was sufficient for me to easily identify storm-scale processes. 2 - The vertical coverage of the radar data was sufficient for me to be confident in the warnings I issued. 3 - I would prefer increased vertical coverage (i.e., more elevation angles) compared to what I saw during this case.
Please rate how much you agree or disagree with the following statements based on your experience working this case. [MATRIX TABLE; Strongly disagree; Somewhat disagree; Neither agree nor disagree; Somewhat agree; Strongly agree; RANDOM ORDER] 1 - The velocity data depicted important features clear enough for me to be able to easily identify storm-scale processes. 2 - The velocity data depicted important features clear enough for me to be confident in the warnings I issued. 3 - The data clarity/texture of ZDR, CC, and KDP for the radar data was sufficient for me to easily identify storm-scale processes. 4 - The overall data clarity/texture of ZDR, CC, and KDP for the radar data was sufficient for me to be confident in the warnings I issued. 5 - I would prefer improved dual-pol data clarity/texture (i.e., less noise in the dual-pol variables) compared to what I saw during this case.
Overall, how useful were the radar data in allowing you to identify key storm features that were important in your warning decision process? 1 - Not at all useful 2 - Not very useful 3 - Somewhat useful 4 - Very useful 5 - Extremely useful Please briefly explain why you chose your answer to the above question. [OPEN RESPONSE]
Overall, how confident were you in the warnings you issued during this case? 1 - Not at all confident 2 - Not very confident 3 - Somewhat confident 4 - Very confident 5 - Extremely confident Please briefly explain why you chose your answer to the above question. [OPEN RESPONSE]
Thinking about this case overall, would you say the resolution was: [RANDOM ORDER] 1 - Acceptable, it could even have a lower resolution and it would still be usable

2 - Acceptable, but any lower resolution and it would not be usable 3 - Unacceptable, there needs to be higher resolution for the data to be usable 4 - I am not sure
End-of-week surveys
Please rate how much you agree or disagree with the following statements regarding the radar data you used this week. [MATRIX TABLE; Strongly disagree; Somewhat disagree; Neither agree nor disagree; Somewhat agree; Strongly agree; RANDOM ORDER] 1 - Overall, I preferred the vertical coverage (i.e., number and spacing of elevation angles in a volume scan) of the KATD data over the KTLX/KOUN data. 2 - Overall, I preferred the dual-pol data clarity/texture (i.e., nosiness of the radar variables) of the KATD data over the KTLX/KOUN data. 3 - Overall, I preferred the volume update time of the KATD data over the KTLX/KOUN data. 4 - Overall, I preferred the 0.5-degree elevation angle update time of the KATD data over the KTLX/KOUN data. 5 - Overall, I preferred the velocity data of KATD over KTLX/KOUN.
Please briefly describe the biggest factors that impacted your warning confidence throughout the week. This could include characteristics of the radar data itself, characteristics of the case (e.g., number of storms, storm mode), or other factors. [OPEN RESPONSE]
Please rate how much you agree or disagree with the following statements regarding the KATD data you used this week. [MATRIX TABLE; Strongly disagree; Somewhat disagree; Neither agree nor disagree; Somewhat agree; Strongly agree; RANDOM ORDER] 1 - My radar interrogation strategies changed throughout the week to adjust to the KATD data. 2 - My comfort level using KATD data increased throughout the week. 3 - Overall, the volume update time of the KATD data was too fast. 4 - Overall, the low-level (i.e., 0.5-degree elevation angle) update time of the KATD data was too fast. 5 - My mental workload (i.e., available mental capacity to dedicate to a given task) decreased as the week progressed. 6 - The rapid-update KATD data was overwhelming in terms of my mental workload (i.e., available mental capacity to dedicate to a given task).
Did how you interact with the phased array radar data change as the week progressed (e.g., did you use AWIPS differently, did you progress through the radar data differently, did you alter what aspects of the radar data you focused on, did you alter your procedures at all, etc.)? [RANDOM ORDER] 0 - No 1 - Yes

Please briefly explain your answer to the previous question. [OPEN RESPONSE]
Please briefly describe the biggest factors that impacted your mental workload (i.e., available mental capacity to dedicate to a given task) throughout the week. This could include characteristics of the radar data itself, characteristics of the case (e.g., number of storms, storm mode), or other factors. [OPEN RESPONSE]
Please briefly describe what you thought were the biggest positives of the phased array radar data you interacted with this week. [OPEN RESPONSE]
Please briefly describe what you thought were the biggest negatives of the phased array radar data you interacted with this week. [OPEN RESPONSE]
What would your ideal volume update time be while working a severe hail* event at your home forecast office? 1 - 10–20 sec 2 - 21–40 sec 3 - 41–60 sec 4 - 1.0–1.5 min 5 - 1.6–2.0 min 6 - More than 2.0 min *Same question asked for wind, busy tornado, and normal tornado event
Please indicate about how often (if at all) you typically use radar data at the following approximate height levels while interrogating storms for severe hail potential and/or issuing severe thunderstorm warnings for hail*. [MATRIX TABLE; Never; Seldom; About half the time; Most of the time; Always RANDOM ORDER] 1 - The 0.5-degree elevation angle (lowest possible height) 2 - The lowest 1–3 elevation angles (low levels) 3 - An elevation angle near the 0C height (mid levels) 4 - An elevation angle near the -20C height (upper levels) 5 - An elevation angle near storm top *Same question asked for wind and tornado events
Is there anything else you would like to share with us about PAR that you have not already had the opportunity to? [OPEN RESPONSE]