12B.4 2010 PHASED-ARRAY RADAR INNOVATIVE SENSING EXPERIMENT

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1. INTRODUCTION

Advancements in the rapid-scan capabilities of the National Weather Radar Testbed Phased-array Radar (NWRT PAR; Zrnić et al. 2007) developed at the NOAA National Severe Storms Laboratory (NSSL) were demonstrated during the 2010 Phased-array Radar Innovative Sensing Experiment (PARISE) via two components: radar data collection and National Weather Service (NWS) forecaster warning decision making. The NWRT advancements demonstrated during data collection include upgrades to signal processing capabilities and software that take advantage of this unique instrument (Torres et al. 2011). The most significant upgrade in terms of reducing update time was the implementation of a range oversampling technique called adaptive pseudowhitening, which reduces sampling time by about 50% while maintaining, and in some cases improving, estimation errors (Torres and Zrnić 2003; Curtis and Torres 2011). The addition of enhanced, situation-driven adaptive scanning techniques further reduced volumetric update times to as short as 30 s for the 22-elevation scanning strategy described herein, and resulted in minimum update times near 8 s at low elevation angles when tornadoes where occurring near the NWRT PAR. Section 2 of this paper describes these enhanced adaptive scanning techniques and gives an overview of weather events sampled in spring 2010 (April – mid June).

The objective of the second component, NWS forecaster warning decision making, is to develop and pilot the first study designed to examine and understand potential impacts of update time on the NWS warning decision process. Given the capability to better sample the rapid evolution of severe weather events (Heinselman et al. 2008) it is important to study how the utility of this additional information may translate into NWS operations. We accomplished this objective during the last three weeks of April 2010 thanks to the participation of 12 forecasters from 3 of the 4 NWS regions. The experimental design is found in section 3, while analysis methods and preliminary results are found in sections 4 and 5.

2. ENHANCED ADAPTIVE SCANNING

In spring 2010 a 22-elevation scanning strategy provided the baseline method for sampling storms. Following the implementation of adaptive psuedowhitening (Curtis and Torres 2011), this “oversampled VCP” sampled storms with a maximum update time of ~60 s, while providing enhanced azimuthal sampling at all elevations, enhanced vertical sampling near the radar, and good data quality. Enhanced sampling in azimuth was achieved by employing 50% overlapped azimuthal sampling in a manner similar to super-resolution sampling described in Brown

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et al. (2002). Because the beam width varies across the sector, the oversampling is adjusted accordingly (0.75–1.05°). The number of azimuthal beam positions is 55 without oversampling, and increases to 109 beam positions with the 50% oversampling employed here. The number and spacing of elevations were based on vertical sampling criteria developed by Brown et al. (2000) to "optimize" vertical sampling. In Brown et al. (2000), optimized vertical sampling occurs when the "maximum height uncertainty (expressed in percent of true height) is essentially the same at all ranges and for all heights of storm features." This sampling approach provides denser sampling at low altitudes, where it is needed most. In PARISE 2010, a maximum height uncertainty of 18% and sampling of storms through 18 km above ground level (AGL) were desired through a minimum range of 20 km from the NWRT PAR. Following the approach of Brown et al. (2000), these criteria resulted in a VCP with 22 elevations (Fig. 1). Batch-like processing was run below 6° in elevation to minimize range-folded weather returns.

The backbone of the NWRT PAR's automated electronic adaptive scanning capability is the Adaptive Digital Signal Processing Algorithm for PAR Timely Scans (ADAPTS; Heinselman and Torres 2011). In brief, the ADAPTS ingests the operator-chosen scanning strategy and optimizes the scanning update time by only sampling beam positions, and a user-defined neighborhood around them, with significant weather returns (Heinselman and Torres 2011). This basic, automated approach to adaptive scanning provides the most significant improvements in update time (~30%) when storms are relatively small, isolated, and located at ranges far from the radar. Knowing that the development of severe weather near the ground can occur on the order of minutes to seconds, and that in a multifunction environment radar resources may be shared (Weber et al. 2007), additional manual situation-driven adaptive scanning techniques were employed to test their use in further reducing update time.

Situation-driven-adaptive scanning further reduced update time by adjusting scanning strategy waveform and/or the number of elevation angles based on storm location and the potential for tornadogenesis (Table 1). For example, when storms were located only within 120 km of the NWRT PAR, the volumetric update time was reduced by about 30% by changing the waveform from batch to uniform at all elevation angles and setting all pulse repetition times (PRTs) to 800 μs. These changes reduced the volumetric update time from ~1 min to 40 s. When tornadogenesis was possible (e.g., supercells or QLCSs were occurring), more rapid sampling within the lowest 1–2 km was achieved by consecutively sampling the storm with only the lowest two or four elevations two times, followed by a complete volume scan. This focused sampling strategy rapidly sampled the storms (8–22 s updates) at altitudes where tornadic vortex signatures may indicate the presence of a tornado. The two lowest elevations were used only when all storms were located more than 120 km from the NWRT PAR, and resulted in 12 s low-elevation updates. The four-elevation scanning strategy produces 22 s updates that were reduced to 8 s when storms were located only within 120 km of the NWRT PAR due to the implementation of uniform PRTs.

The data collection techniques described above were employed 1 April through 15 June 2010. Eleven events were sampled, including a high-wind and hail-producing QLCS on 2 April (Newman and Heinselman 2011) and a tornado outbreak on 10–11 May (Smith et al. 2011). Examination of some of

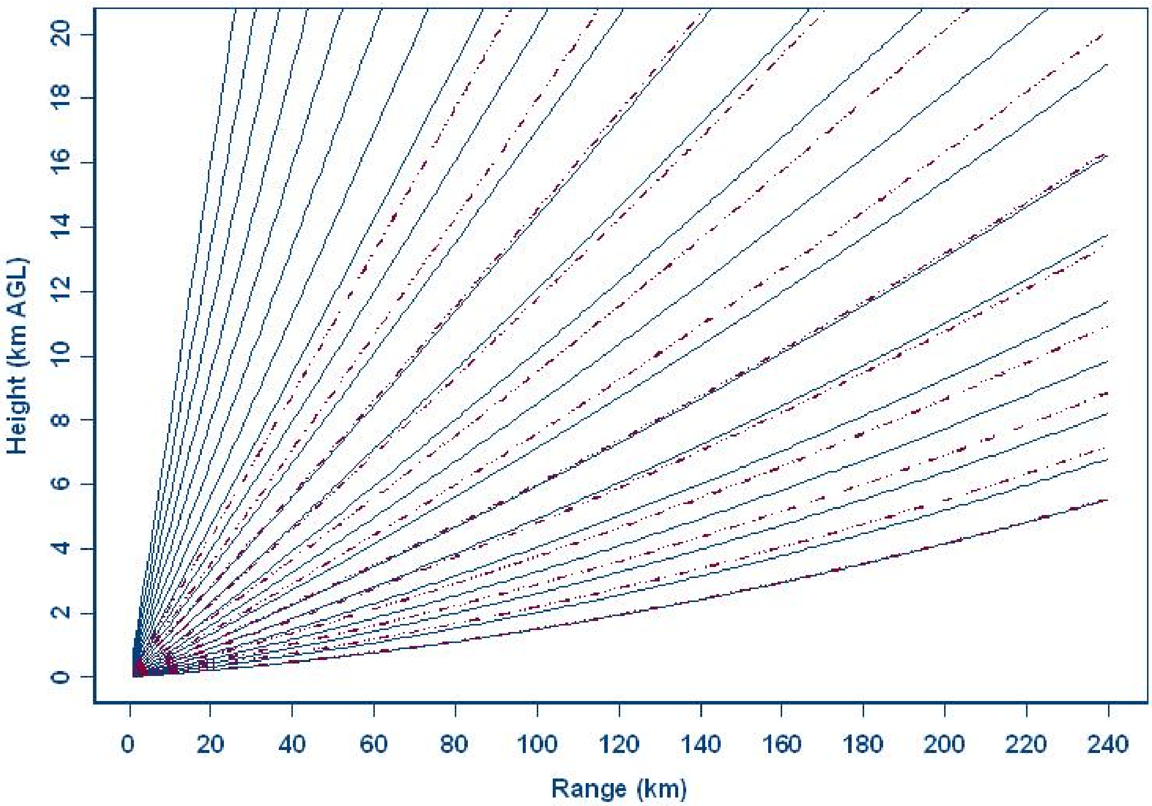

Fig. 1. Elevation angles of the oversampled VCP (blue lines) shown with VCP 12 for comparison (red dash-dot lines).

Table 1. Basic description of VCP attributes with range oversampling.

VCP	# Tilts	Waveform	Update Time (s)
Oversampled_VCP	22	Split cut < 6°	60
Oversampled_VCP_within_120km_only	22	Uniform	40
Tornadic	2	Split cut	22
Tornadic_outside_120km_only	4	Split cut	12
Tornadic_within_120km_only	4	Uniform	8

Table 2. Summary of weather events sampled by the NWRT PAR during spring 2010.

DATE	Event
2 April	Wind event with hail and possible tornado
6 April	Rapid init squall line along front & dryline with hail
22 April	Quasi-linear Convective System
10 – 11 May	Tornado Outbreak over Central OK
12 May	Quasi-linear Convective System
14 May	Multi-cellular Convection
16 May	Significant Hail over OKC
19 May	Cyclic Tornadic Supercells north of OKC
26 May	Multi-cellular Convection
30 May	Significant Hail north of OKC
14 June	Multiple Quasi-linear Convective Systems

these events is underway and will be reported on in later papers.

3. IMPACT OF UPDATE TIME ON NWS FORECASTER DECISION PROCESS

The primary objective of the NWS forecaster component of 2010 PARISE was to both develop the groundwork for and begin to build an understanding of potential operational impacts of update time on NWS forecasters' warning decision process and warning lead time. This user-focused part of the experiment took place during the last three weeks of April 2010. The section describes participant selection and demographics, the NWRT PAR data sets, and the experiment design.

3.1 *Participant Selection and Demographics*

Participants were recruited via an e-mail invitation distributed to National Weather Service Forecast Offices across the nation by the five NWS Regional Offices. Following a brief description of the experiment, the recruitment letter asked respondents to explain in writing their interest in participating in the 2010 PARISE. The primary applicant pool contained 34 NWS forecasters; 94% were from offices located in the Central, Eastern, or Southern Regions, and the 12 participants were chosen from these 3 regions (Fig. 3).

The selection of the twelve participants was based on the content of their written interest statements, location of their home office, and experience with radar data. Forecasters whose interest statements provided evidence of aptitude for reflective thinking and experience evaluating weather products and display tools were given priority over others. We then examined information on years of experience to determine a first guess at forming teams that would balance during each week of the experiment. We also considered sex of the applicants in the interest of representing that aspect of demographics. We were not able to form a set of participants from all regions, but took into account location in the country to incorporate geographic (and thus weather) diversity: southwestern, southern plains, midwestern including both flat and hilly regions, and northeastern portions of the country.

The 12 participants included 3 females and 9 males from NWS offices located in 11 different states east of the Rocky Mountains (Fig. 2). As mentioned above, diversity in office locations brought together forecasters with experience issuing warnings on storms whose development is impacted by different climatologic conditions and terrain features. Additionally, most participants, 11 of 12, had worked at two or more offices in different geographic regions. The number of years experience working in the NWS ranged from 5 to 23, with an average of ~12 years of service (Fig. 2). Four of the 12 participants had held positions in private industry 1.5 – 5 yrs before being employed with the NWS. At the time of the experiment, 11 of the 12 participants were in forecaster positions, and one was a meteorologist in charge. All participants had experience issuing warnings for severe weather, and most (7) had several years experience having consistently worked the warning desk during severe events.

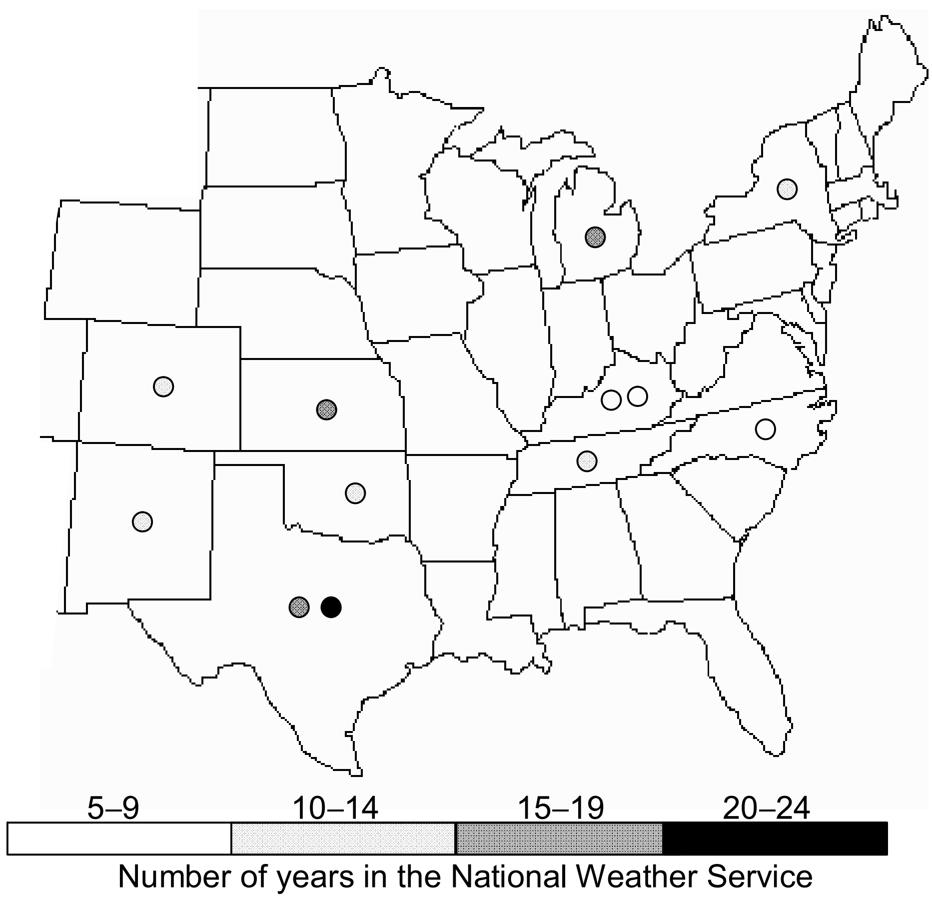

Fig. 2. Circles indicate the states, but not the specific city, where participants' home offices were located. The number of years employed in the NWS is color coded according to the grey scale shown.

3.2 *NWRT PAR Data: 43-s and 4.5-min updates*

To examine the idea that update time may have an impact on participants' warning decision process, for each playback case NWRT PAR data were used to create two data sets with different update times: one with the full-temporal resolution (43-s updates), and the other with simulated WSR-88D-like temporal resolution (~4.5-min volume scan with elevations updating through that time period). The simulated 4.5-min volume scans (hereafter 4-5 min updates) were constructed by 1) determining 4.5-min update times for each elevation (14 total) over the case duration, 2) matching the nearest-in-time NWRT PAR elevation to these revised times, and assigning the new time stamp to each elevation. Hence, in most instances the time stamps of simulated data do not coincide with those of the original, full-temporal resolution data. The use of NWRT PAR data was key to the experiment design because identical spatial sampling characteristics supported apples-to-apples comparisons of the storm evolution. This methodology was applied to two supercell events of relatively short duration (45 min – 1 hr) that produced weak tornadoes. This type of event is one of several phenomena that occur on a time scale at or below the update time of the WSR-88D.

3.3 *Experiment design*

This study generally followed a matched-pairs, control-group design (Mertens 2005), though matches were on teams of two rather than individuals. The experimental group saw the full temporal PAR data and the control group saw PAR data degraded to the update characteristics of the operational WSR-88D. Given the small number of participants and no reliable, objective way to assess radar data interpretation and warning decision making skills, the matching was approximate. Earlier in the week, participants had rotated through partners to work together through three events, and so had gained a sense of each other's knowledge and skills. One of us (Heinselman) had been working with the forecasters on these previous days and suggested groups. We explained we were seeking to have teams that were roughly equivalent in regard to radar data interpretation skills. All were agreeable. The debriefing plans allowed room for them to tell us if they felt their groups had been notably unequal. None did. The plan for this study was approved by The University of Oklahoma's Office for Human Research Participant Protection (a.k.a. Institutional Review Board).

Four NWS forecasters participated each week of the experiment, which ran from midday Tuesday through Friday morning. Through Wednesday they participated in activities developed to build forecaster experience using the Warning Decision Support System – Integrated Information (WDSS-II; Lakshmanan et al. 2007) display software to analyze NWRT PAR data and issue warnings prior to the more intensive, day-long "Impact of Update Time on Warning Decisions Experiment" held on Thursday. The WDSS-II was used in lieu of the Advanced Weather Interactive Processing System (AWIPS) due to the operational software's inherent inability to display data sampled with an update time of 1-min or shorter. We sought to minimize the impact of software differences on the experiment outcomes by upgrading the WDSS-II with WARNGEN functionality similar to AWIPS, and by providing forecasters with hands-on training and three experience-building playback cases using the WDSS-II display. The three NWRT PAR playback cases included a microburst, quasi-linear convective system, and an isolated supercell. After each event, forecasters subjectively compared storm evolution depicted by PAR to that depicted by the near-by WSR-88D (KTLX), discussed their warning decision making process with facilitators, and were given ground truth to assess whether their warnings verified.

On the day of the study, participants worked through two weather cases as if they were on the job, issuing weather warnings and updates. The first case was a supercell that formed in a marginally severe Southern Plains environment and produced an EF0 tornado on 14 May 2009 (NCDC 2009). The second case was a low-top supercell that formed in a tropical environment and produced an EF1 tornado near Norge, Oklahoma on 19 August 2007 (damage survey available at: http://ewp.nssl.noaa.gov/projects/shave/tornsurveys.php#map). At the start of each case they had approximately 20 min to review weather data to gain situational awareness. They then wrote a discussion about what they thought would happen in the next hour or so. Each case then ran in a displaced real-time mode. One was about 45 min, the other about 1 h. Forecasters were observed and audio recorded; their computer screens were video recorded (all participants provided consent for all of these). Computer files of the discussion text and warning related texts were archived on the computer. After each case was completed, a debriefing was conducted with each group independently. Forecasters were invited to take notes on critical decision points to use in the Joint Debrief. They were asked to rank factors in importance to their decision making and to rate their confidence relative to usual on two continuums: one for the type of event and one for the impact of the radar data. Finally, all participants come together to discuss their experience with the data and its impact on their warning decisions. Between cases, participants had a break for lunch. After the last case they were asked for summary information on their work histories that might be relevant to interpreting differences in their warning decisions.

3.4 *Limitations*

Other designs were considered. Previous studies of forecasters used cognitive task analysis type methods, mainly on military forecasters. One study focused specifically on warning decision making of National Weather Service warning forecasters. Hahn et al. (2003) used the critical decision method to probe forecasters in depth about warning decisions. The method has proven useful in studying individual decision making in other disciplines, though the lack of definition of an expert forecaster has confounded these types of studies. Recent literature on decision making builds a strong cause for only studying decision making in natural settings (Schraagen et al. 2008), as Joslyn & Jones (2008) did with Naval weather forecasters creating terminal aerodrome forecasts. However, it is not generally possible to introduce experimental datasets into operational NWS forecast offices. We also sought to have multiple instances of the same case comparison to analyze, meaning case data had to be used. Although we simulated several aspects of an operational setting and asked forecasters to attempt to work as closely as they would to normal, it is difficult to truly simulate the tension, distractions, and other aspects of operations in a case study.

4. ANALYSIS METHODS

Data analysis involved several steps to process and make manageable the data yielded from transcriptions of audio and visual recordings, as well as researchers' notes and the self-reported confidence continuums. Using standard practices for the treatment of social science data, the data processing involved (1) editing the transcriptions for transcription error and (2) coding the data to extract meaning. Editing is a quality control measure that ensures the treated data is an accurate record of the experiment (Singleton and Straits 2005). The editing stage entailed reviewing the transcriptions to correct errors in the transcripts where they did not accurately capture the dialogue during the experiments. Editing in this case was particularly important where sophisticated meteorological terminology and nuanced explanations may have been difficult to capture in the initial transcription process.

Coding makes the data manageable by classifying it according to analytic categories and predominant themes (Bernard 2002). The coding process translates the data into a set of nominal variables involved in the warning decision making process. We followed a data-driven approach to the analysis, which means that analytic categories were identified inductively (Boyatzis 1998). A coding scheme was developed based on categories that emerged in the data, as well as categories that would address the research questions. We began by identifying major categories such as expression of state, cognitive action, and meteorological, environmental, or other data being examined as well as reflections on the experiment design. Forecasters expressed their mental state, for example expressing concern; forecasters demonstrated a cognitive action, for example interrogating; forecasters considered meteorological or other factors in the data available to them in the experiment, for example inflow; forecasters also reflected on the design of the experiment, for example the unfamiliar setting and software. Sub categories within these themes were used to refine the analysis with higher specificity. Three researchers are coding the data. Intercoder reliability will be tested as we progress through the data by having sections of the data coded by more than one person. Finally, we will examine how the substantive categories are related and build a conceptual model of the influence of higher-temporal-resolution radar data on forecaster decision making in the warning process.

The video recordings visually documented interactions of participants with the WDSS-II and WES display and the specific radar fields and features or other observations they were viewing during each case. In coordination with the transcripts, this visual information was used to augment, clarify, and confirm coding of cognitive actions and states of being of participants, as well as issues related to experimental design. The use of video information, for example, illustrated the series of radar moments and radar signatures viewed, interrogated, or interpreted by participants preceding each warning decision.

5. OBSERVED WARNING DECISION MAKING: SAMPLE CASE, 19 AUGUST 2007

5.1 *Case Overview*

During 01:13–01:58 UTC 19 August 2007 the NWRT PAR sampled two low-top supercells as they moved north-northeastward from southwest Oklahoma toward west-central Oklahoma (Fig. 3). These supercells formed a few hours prior to the reintensification of tropical storm Erin (Arndt et al. 2009). A damage survey revealed that between 0144–0147 UTC the north-most supercell produced a short-lived EF1 tornado with a path 40 yd wide and1.26 mi long that removed the roof of a mobile home and snapped branches in the vicinity of Norge, Oklahoma (Storm Data 2007). The storm evolution described later in this section focuses on this torandic storm.

The storms were sampled within a 60° sector using a scanning strategy that employed the same elevation angles as VCP 12 (NOAA 2006) and 0.5° overlapped azimuthal sampling (Heinselman and Torres 2011). The implementation of an electronic scanning technique called beam multiplexing (Yu et al. 2007) resulted in 43-s volumetric updates. As mentioned in section 3, during the simulation one team received this 43-s volumetric data, while the other team received 4.5-min volumetric data derived from the NWRT PAR data set. As a result, during the period of one VCP 12 volume scan, the rapid update team received 6 volumetric updates.

The 4.5-min updates indicate that during the 45-min case the tornadic supercell occluded twice, first between 01:14–0125 UTC (Fig. 3a–d), and 20 min later between 0145–0154 UTC (Fig. 3h–j). It is during the second occlusion (0144–0147 UTC) that the tornadic vortex signature (TVS) of the EF1 tornado (0144–0147) develops. During the tornado lifetime, the TVS is sampled at the 0.5° elevation once within the 4.5-min data (Fig. 3h), and four times within the 43-s data (Fig. 4); maximum velocity differences ranged from 47.5–51.5 m s^{-1}. The 43-s data confirm, and show in greater detail, the occlusion process coincident with tornado occurrence (Fig. 4). In a warning situation, though, forecasters would ideally issue a tornado warning prior to its occurrence. The warning decision processes and tornado warning lead times resulting from the temporally different data sets follows.

5.2 *Warning Decision Making Process*

Analysis of the audio and actions of the 4.5-min update team reveals considerable warning decision uncertainty. This team was wary about the situation from the outset, knowing that tropical systems tend to produce weak, rapidly evolving tornadoes. They were initially uncertain which storm to focus on and what to expect to see in terms of the strength of the signatures: both storms exhibited some semblance of a "kidney bean" shape at the outset of the case but little rotation. They interrogated the strength of inflow, height of the storm tops, velocities across any circulation features they could identify, depth of reflectivities in the storms, velocities aloft, and convergence as seen in cross sections through the storms. Carl[1] initially liked the look of the southern storm better, while Allen occasionally asked for information about the northern storm.

They focused on the southern storm and occasionally monitored the northern storm. Using a cross-section view on PAR image 1:17:52 UTC Carl saw some velocity enhancement in the notch on the southern storm and said, "That looks interesting there."[2] He read off, "31–30 kts" and jokingly asked, "Can we issue tornado warnings on EF negative 1 tornadoes?" Allen asked how the northern storm looked. They determined that it was stronger than the southern storm, but not as deep. They hoped to get some ground truth on a warning issued on a storm outside of the NWRT PAR domain just before their case began. They began to discuss what they expected to see in this case and recalled that the storm that had been warned had had a stronger couplet than what they have seen thus far. They interrogated.

The team dynamic was affecting the overall decision process, but also was adding insight into the spectrum of

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[1] Names used are pseudonyms.
[2] Quotations are their exact words.

thinking and analysis strategies among warning forecasters. Carl, excited to get a base velocity cross section working, scoffed at the low values he saw. Allen countered, "Sometimes that's all you get with these," and went on to mention recent experience with a tropical storm that produced many tornadoes in his CWA. Carl agreed, but said he would like to see "at least about 40 kts." He wasn't sure the storm was severe yet. Allen pointed out that in a tropical situation, the storms may not ever reach severe criteria—except for the brief tornadoes they produce. At this moment, with the PAR image timestamp of 1:22:19 UTC (Fig. 3c) in front of them, they pondered if they should issue a warning on the northern storm. As PAR image 1:26:46 UTC (Fig. 3d) came in, they looked again and Carl said, "I don't see anything in the northern one." Allen agreed a feature had degraded: "Yea, it doesn't look quite as good." They appeared close to a warning decision, but did not initiate WARNGEN. The 43-s data team had just issued a warning on the northern storm, but this team did not know that.

While still on the PAR image from 1:26:46 UTC (Fig. 3d) they initiated a storm relative velocity display. In the process of looping data to determine storm speed and direction, Carl noted, "Looked good there, then it kind of fell apart." Allen agreed, "Yea, that was probably a little F0 there." Shortly after this the two switched places so that Allen was controlling the mouse. [In pre-case discussion, a researcher asked if they were in the chairs they wanted to be in. Allen responded, "Well, we kind of shared both responsibilities" and Carl agreed.] Allen appeared to retain some uncertainty as he interrogated the SRM data up to PAR image 1:26:46 UTC. "So based on SRM," he said, "I think, again *if* these are tornadoes, they have already occurred. So I think at this point, I'm more inclined not to warn[3]."

The team's first issued warning decision process follows shortly after this point. They expected the storms to recycle, and watched for that to occur. As PAR image 1:31:13 UTC (Fig. 3e) came in, Allen interrogated reflectivities up to about one thousand feet above ground. Returning to the lowest elevation he said of the northern storm, "Hmmm.... I don't know. That still looks kind of big." He pulled up spectrum width and MESH, momentarily surprised with the software that the MESH came up, "Oh, didn't we figure out how to get rid of this?" Switching his attention back to interpretation he stated, "I like that," while pointing to a velocity couplet on the northern storm. Continuing, he said, "That's the southern one, isn't it?" This team was plagued with both software distractions as well as difficulty deciding which storm to be most concerned with. Ultimately, the radar data itself was clear enough for them to make their warning decisions on the northern storm.

After assuring himself that he was on the most recent image (PAR 1:35:41 UTC, Fig. 3f), Allen initiated WARNGEN. Over the next six minutes and five seconds he struggled to place the dot and set the storm motion. Just as he finished setting a path he liked, PAR updated to 1:40:08 UTC (Fig. 3g) and he said, "Oh, now it looks like crap again." Despite our best efforts, teams continued to have some issues with the display software because they did not always know how to quickly display what they wanted to see. Had this team been able to issue the warning at this point, they would have had about 8-min lead time.

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[3] The italicization of the word "if" portrays his verbal emphasis.

While recollecting their thoughts, Carl noted that the movement of the northern storm appeared to be more to the north. Allen agreed that had "confounded" him as he set his path in WARNGEN. On PAR image 1:40:08 UTC (Fig. 3g), Allen decided to look for a velocity enhancement signature at about 10,000 feet. Over the next 3 min he again had issues with the software and was unable to pull up a cross section of velocity.

When the PAR lowest elevation scan of 1:44:35 UTC (Fig. 3h) came in, Allen exclaimed, "....Ooo! Guess what!" and Carl laughed loudly. They quickly initiated WARNGEN and issued a tornado warning about 40 s later. Afterward Carl chided Allen, whispering, "That means you missed it." Allen responded, "Yea, welcome to tropical stuff." The case is not yet complete, but as in other weeks, we observed a reflection period in the immediate moments after a warning product was issued. Carl turned and said to one of the researchers, "This is very interesting, 'cause you're going to catch all these little spin ups with the one-min data." Allen added, "That's what we're hoping."

The team with 43-s data oriented very quickly to the software and the event. They immediately changed the display panels to what they wanted to see. Bob controlled the radar and appeared very comfortable both with the software and with how to analyze the situation. Within the first minute, he had a loop of the data displayed. Joe noted the storms appeared to moving northward. "That makes sense, though," he said, apparently considering how that surprised him, yet matched a mental model. This team immediately focused on the northern storm, and periodically checked the southern one.

Bob also appeared to work off mental models and continually checked the base velocity and reflectivity data to confirm them. As he interrogated the storms in height, he confirmed they were shallow. He identified "a little bit" of convergence at 3,000 ft above ground in the northern storm, and the "best inflection" of 50 kts at 13,000 ft. Joe responded to these observations with, "It's almost like it's a tornado or nothing, right?" Bob agreed, "Absolutely. There is no severe in this." Right from the start, this team focused on the northern storm, agreed upon what they saw, and began a pattern of building upon each other's thoughts to help them zero in on the correct location and the correct threat. They maintained situational awareness on the southern storm, with Joe noticing a "bit of rotation" in it as early as PAR image 1:18:30 UTC (images not shown to meet document size requirement).

Also on the 1:18:30 UTC data, Bob queried velocities and found 58 kts inbound. Interrogating both reflectivity and velocity, he observed, "Here's a little bit of rotation right in that little notch right there. You see that?" He continued, "That's what I would consider my preferred location." On the PAR image 1:19:13 UTC, he looked at both storms, and pointed out the area he was concerned with on each. Joe agreed and added that the low-level winds were feeding right into that area.

At this point Bob vocalized he was looking for a velocity trend. "Okay, so now, if I go back one, we're at 3 and 7 [kts]. [PAR=1:19:56 UTC] Now, we go forward, now we're up to 10, 11, going outbound. And still 32 going inbound." He then zoomed in and said, as if thinking out loud, "'Cause, really, this is what's important. I don't need to look at anything else." Joe agreed, "It's right on that little notch." As PAR data 1:20:39 UTC came in, Bob looped the data again to ascertain storm motion. "If this is developing, we're going to need to know how we want to draw something," he said. Joe noted the data were updating very quickly: "The times update so fast. Let's see where we are here... 1:20."

A new image, PAR=1:21:22 UTC arrived and Bob noted the trend was continuing upward: "now we are up to about 25." They agreed that with this type of system they were not likely to see 50 kts inbound and outbound. Joe adds that the low LCL and low level CAPE can stretch vorticity quickly into a tornado. When PAR=1:22:05 UTC came in, Bob noted the southern storm was also trending upward. Joe appeared to surprise Bob when he said, "No reports...at the moment." Bob responded, "What's that?" Joe reiterated, "No reports coming up at the moment", and then refocused on the radar data.

At this point they began to build toward the warning decision. Joe pointed out, "Okay, there it's tightening up a little bit. Right in there." Bob agreed and built upon the idea, saying, "And that's been persistent. You know, this has been persistent. So..." Joe then asked if the tightening circulation corresponded to "it" (presumably a reflectivity notch) and Bob said, "Yup, 41. And that's where I'm concerned... It doesn't take much." Joe then said, "I'm okay with starting a tor on that." As they initiated WARNGEN, Joe added, "'Cause I think being aggressive in this environment is a good thing to do. Something is going to come out of there, you know." They briefly considered how long the warning should last and proceeded to issue the warning on PAR image 1:23:31 UTC. They did not experience problems with WARNGEN, and issued the warning just over two minutes later with 21 min lead time.

In the immediate moments after issuing their warning they continued to see support in the data, and then checked on the southern storm to "make sure nothing is going on," as Bob put it. That storm was still weak aloft. They also checked spectrum width, which Bob stated is unable to resolve the motion. Joe then expressed an underlying hope of rapid update volumetric data: "If we could see one spin up and get some good lead time on it, that would be awesome." But their warning was not issued on hope. Bob looked again at trends, "Let's see here... 1:18:30, 1:19:13, 1:19:46. That was the most impressive one right there. But...they pulse up and down very quickly."

As the case progressed, they interrogated the strength of the circulation in the northern storm, evaluated the size of their warning polygon and monitored the southern storm. The circulation in the northern storm continued to trend upward. Bob noted "Inbound-outbound...15 and 48" on PAR 1:29:15 UTC, then, "44. Now it's up to 44. And 12, almost 13 kts outbound" on PAR 1:29:58 UTC. After Joe observed the southern storm was still "not doing anything too crazy," and continued, "I'm pretty comfortable right now with what we've got going." Bob agreed, and commented that normally he would consider reducing the warning polygon, but the southern storm had potential to move into the warning and intensify. "I don't know if I want to [reduce the size of the polygon] right now," he said, however, and wondered aloud if there was some environmental feature not resolved in the data that was affecting tornado potential.

Over the next 12 min, their confidence continued. By PAR image 01:32:07 UTC, Bob declared, "There is absolutely something going on there [in the northern storm]." They consulted environmental data and monitored the southern storm. By PAR image 01:35:00 UTC, Bob noted 40 kts of gate-to-gate shear on the northern storm, "pretty good for a tropical system." On PAR image 01:39:18 UTC, they assessed that the southern storm continued to have weak outbound velocities, but 41 kts inbound, "something that we are going to have to consider," Bob said. Joe agreed, "It seems there is kind of a general area of rotation there." However, by PAR 01:40:44 UTC, Bob declared the southern storm had "lost that sharp edge." Joe agreed, adding, "We'll keep an eye on it."

Approximately 2.5 min before the tornado touched down, PAR image 01:41:27 UTC showed a tight area of circulation that this team noticed. Joe said, "That's in the right area," referring to the location of the velocity couplet relative to the reflectivity gradients. "See how rapidly that spun up?" Joe said. On the next update, PAR 01:42:10 UTC, they got excited: "Ooo! Look at it now" and "Oh, wow! There you go." They then initiated WARNGEN to start a warning update, and noted that velocities were now 88 kts inbound and almost 30 outbound: "That's the best we've seen" and "Incredible. Incredible."

They reflected while in the process of issuing the warning update. Bob said, "And again, right where we would expect it to happen." Joe agreed and said, "There is definitely a tor on the ground," adding a bit later,"I didn't expect to see that kind of couplet."

In summary, the 4.5-min update team had difficulty monitoring the cyclic nature of the trends in velocity because of the slower updates. They initially could not determine which storm to focus on and had trouble realizing the storms were moving in a northerly direction. They were able to realize the first apparently nontornadic cycle (no verified tornadoes) early in the event, but only after the fact were they certain it had occurred. Knowledge of that cycle helped them gain an understanding of where the storms were in terms of their evolution. The 4.5-min team would have warned on the second cycle, with about 8 min lead time (Fig 5), had they not had trouble with the software. Ultimately, they nearly missed the third cycle of the circulation and issued their warning with no lead time.

The 43-s team easily applied conceptual models because the frequent radar updates provided data to confirm that processes were taking place. This team clearly saw the first cycling at about 1:23 UTC and issued a warning with 21-min lead time (Fig 5). They continued to have confidence in their warning decision because signals in the data were so clear.

By working in teams the forecasters had opportunity to see and learn the others' decision processes. Other impacts of the team structure on decision making will be identified as analysis continues. This case shows that team structure provided a benefit to the study: the results are less prone to the variations in individual forecaster decision making that confounded analysis of forecasters in other studies (e.g., Hahn et al. 2003; Hoffman et al. 2007; and Pliske et al. 1997).

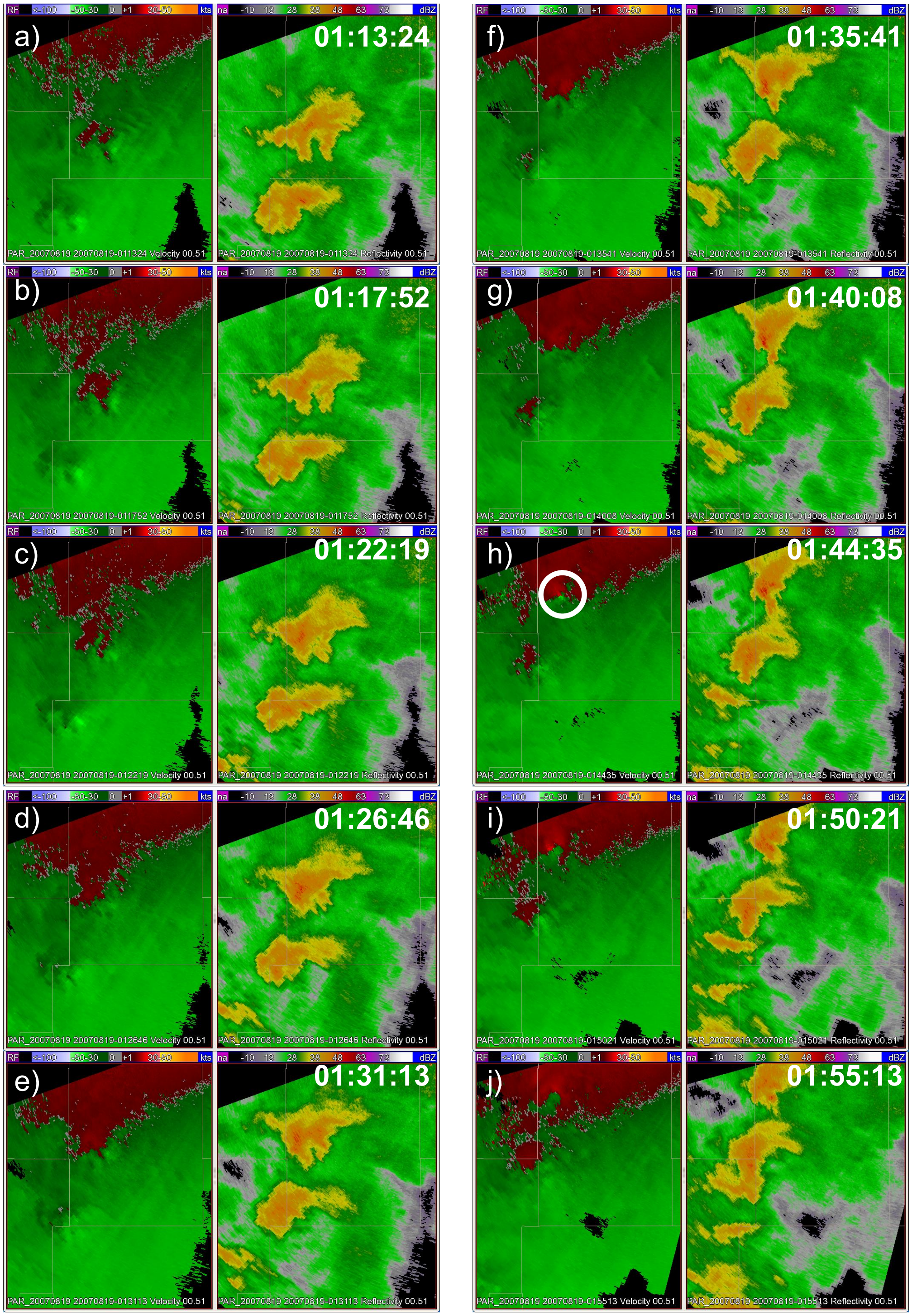

Fig. 3. Time series of 0.5° velocity (left) and reflectivity (right) from 0113–0154 UTC 19 August 2007. The PAR is located in the direction of the upper right-hand-corner and the radar range in the lower left-hand-corner is ~113 km. The TVS associated with the EF1 tornado s enclosed by a white circle.

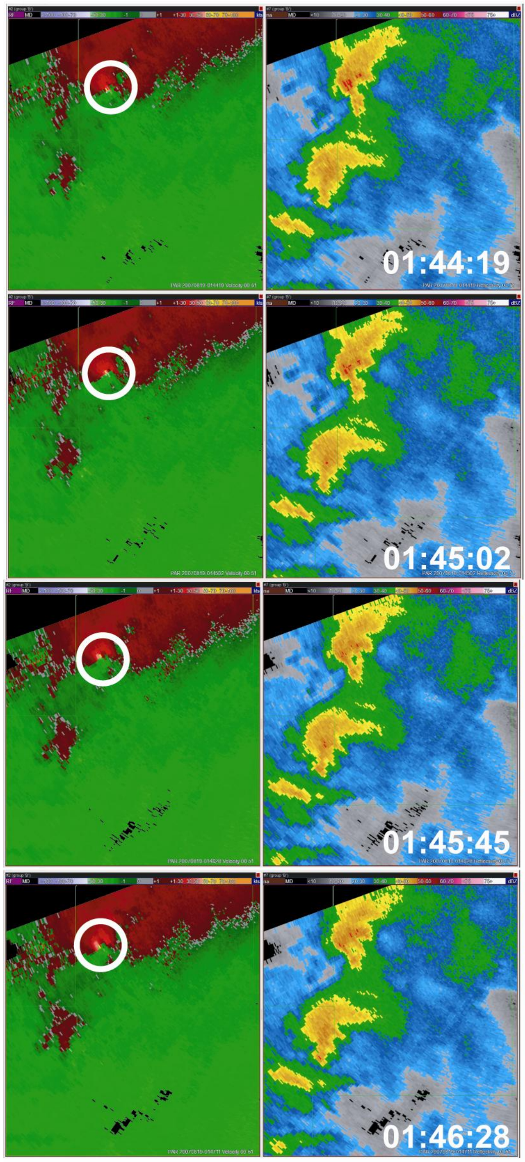

Fig. 4. Full temporal-resolution time series of 0.5° velocity (left) and reflectivity (right) during the EF1 tornado: 01:44:19–01:46:28 UTC 19 August 2007. The PAR is located in the direction of the upper right-hand-corner and the tornadic vortex signatures (enclosed by white circles) are ~60 km from the radar.

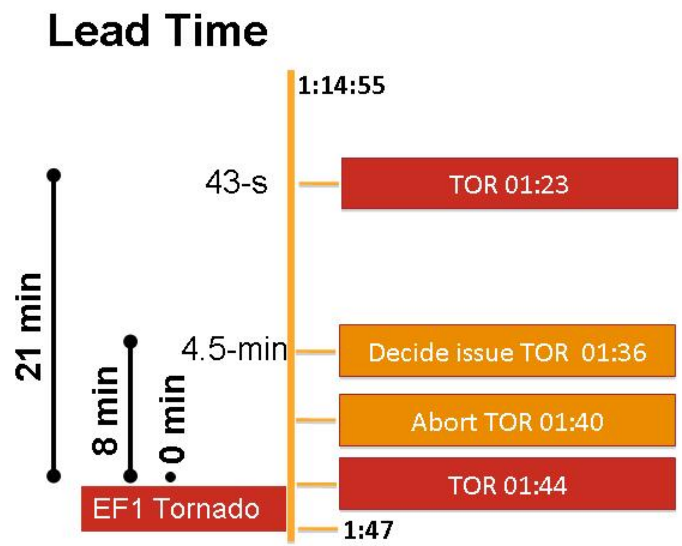

Fig 5. Comparison of decision times for sample case. The Full PAR team had 21 min lead time; the "88D" team would have had 8 min if not for complications. They ended up with 0 min lead time on their tornado warning.

6. SUMMARY and/or REMAINING ANALYSIS

A key objective of the 2010 PARISE was to develop and pilot the first comparative study designed to examine and quantify potential impacts of rapid-update phased-array radar (PAR) data on NWS warning decisions and warning lead time. To meet this objective, forecaster pairs worked two tornadic events in a pseudo-operational setting, one pair received full-temporal resolution (43-s updates) PAR data, while the other pair received WSR-88D-like temporal resolution (4.5-min) data derived from the full-resolution PAR data set. Preliminary analysis of one sample case, 19 August 2007, from of one week of PARISE, shows the use of high-temporal-resolution PAR data resulted in significant improvement in tornado warning lead time: 21 min for the forecaster pair with 43-s updates, and 0 min for the forecaster pair with 4.5-min updates, due in part to software issues. While this is an exciting result, it represents the decision processes of one of three groups that worked the 19 August 2007 event, and the results are driven by analysis of what they did, without consideration of "what they think they did." Our analysis of the transcriptions of the individual and group debriefings will shed light on this latter topic. Analysis of the other groups' warning decision processes and warning lead times on 19 August 2007 and 14 May 2009 are in progress and will be published later this year.

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