# 13B.4 USING THE NWRT PAR TO EVALUATE TEMPORAL SAMPLING DURING TWO RAPIDLY EVOLVING TORNADO EVENTS

Adam J. Smith[1] * Phillip B. Chilson[1], Pamela L. Heinselman[2]
[1]*Atmospheric Radar Research Center and School of Meteorology, University of Oklahoma, Norman, OK*
[2]*NOAA/OAR National Severe Storms Laboratory, Norman, OK*

## 1. INTRODUCTION

The National Weather Radar Testbed Phased-Array Radar (NWRT PAR) is being evaluated as a candidate for the next generation of United States weather radar (Zrnić et al. 2007; National Academies 2008). A major advantage of the NWRT PAR is electronic scanning, which allows for rapid changes in scan settings without antenna movement. Scans are typically restricted to a 90° azimuthal region to limit the effects of beam broadening, so a future version of this system would require multiple antennas to scan a complete 360° volume. However, when using Volume Coverage Pattern 12 (VCP 12; Brown et al. 2005), NWRT PAR can sample a 90° region more than four times faster than a comparable Weather Surveillance Radar-1988 Doppler (WSR-88D) sampling a 360° region (Heinselman et al. 2008). Thus, NWRT PAR may obtain updates much more rapidly than the WSR-88D. These updates may allow for better sampling of storm evolution and location, so guidelines must be established to ensure that rapidly evolving phenomena are adequately scanned.

As a guideline for the Multifunction Phased-Array Radar project, National Academies (2008) define a required update interval of 1 min or better for sampling all weather phenomena. However, Heinselman et al. (2008) have obtained volumetric updates with the NWRT PAR at 30-s intervals. By including techniques like range oversampling (Torres et al. 2011; Curtis and Torres 2011), this update interval could be reduced even further. In these situations, at least 30 s of extra time would be available to perform additional scans. This begs the question: How should we use any extra time? Do we simply perform additional volume scans, or do we consider specialized scans based on the current situation?

In the case of tornadoes, the best answer may be to consider using a specialized scan. Why? Some tornadoes may evolve on the order of 10 s or less (Bluestein et al. 2010) or move at speeds up to 70 miles per hour (31.3 m $s^{-1}$). In these cases, rapid updates of radar scans may improve detection of circulation development or position in real time. Such information can provide earlier warning of tornado development, and also aid emergency managers in determining where to position first responders as the tornado is occurring. From the findings of Heinselman et al. (2008), we expect that an update rate faster than 1 min would be beneficial for sampling tornadic storms. The authors did not examine a tornado case in their study, so an appropriate scanning interval must still be determined.

In this paper, we examine the evolution of tornadic circulations observed during two rapidly evolving events sampled by NWRT PAR. The first event, sampled on 7 May 2008, involved a short-lived EF0 tornado that developed within a mesoscale convective vortex. The tornado developed and dissipated within 5 min, just longer than one WSR-88D scan using VCP 12. With this case, we will attempt to answer the question: Do we get significantly more useful information when using updates of 1 min or less to sample tornadoes? To answer this question, we take NWRT PAR scans with 1-min resolution and degrade them to produce simulated WSR-88D scans with 4-min updates. We then calculate gate-to-gate shear at the circulation center to determine how well the circulation's evolution may be sampled with 1-min versus 4-min resolution. The results are quantitatively examined to assess trends associated with

**Corresponding author address*: Adam J. Smith, Atmospheric Radar Research Center and School of Meteorology, 120 David Boren Dr., Suite 4636, Norman, OK 73072-7307; *e-mail: adam.j.smith-1@ou.edu.*

tornado development and dissipation.

Since we know that volumetric updates of 30 s are possible with NWRT PAR, we propose two more questions. First, if any extra scanning time is available, how might we use it to better sample tornadic storms? Using a strategy developed for the 2010 Phased-Array Radar Innovative Sensing Experiment (PARISE; Heinselman et al. 2011), we discuss several methods for reducing the update time during tornado events. Then we examine NWRT PAR data from an EF4 tornado that caused two fatalities in central Oklahoma on 10 May 2010. This tornado was sampled using update intervals as low as 8 s, so we degrade the data to obtain updates of 15 s, 30 s, 60 s and 240 s at the 0.5° elevation. We then determine the circulation center from velocity data and plot its track. In doing so, we ask the final question: Could 30-s or faster updates improve tracking of tornadoes? By using these rapid updates, we may obtain more information on whether the tornado is changing speed or direction over time. More information on the tornado's track may allow emergency managers to place their first responders closer to the damage path, possibly reducing the number of lives lost during future tornado events.

## 2. EVALUATING CIRCULATION EVOLUTION USING 1-MIN UPDATES

To explore the utility of 1-min updates when sampling tornadic storms, we first examine a tornado event sampled by the NWRT PAR on 07 May 2008. Around 2205 UTC, a mesoscale convective vortex (MCV) formed over extreme northwestern Oklahoma City. Fifteen minutes after the MCV was first observed, a tornado developed within this circulation and persisted from 2221–2226 UTC. According to a storm survey conducted by the Severe Hazards Analysis and Verification Experiment (SHAVE; Ortega et al. 2009), the tornado traveled approximately 4.7 km and was as large as 68.6 m wide. The event was sampled by the NWRT PAR using a strategy with the same elevations as VCP 12. A volume scan was completed every 1 min, while the lowest elevation (0.5°) was sampled every 30 s.

To compare the evolution of gate-to-gate shear sampled by 1-min versus 4-min updates, the original NWRT PAR data are degraded to produce a data set that simulates 4-min update times provided by a WSR-88D using VCP 12. For both cases, the gate-to-gate shear is computed within the circulation at each elevation from 2214–2234 UTC. Results are plotted in time and height with colors to denote the magnitude of shear. The simulated VCP 12 data with 4-min updates (Fig. 1) only provide four volume scans that fall within the analysis period. From 2214–2219 UTC, gate-to-gate shear, initially 10 to 20 m s$^{-1}$, strengthens to 30–40 m s$^{-1}$ between 0.5–1.5 km AGL. This intensification appears to nearly coincide with tornado development at 2221 UTC. However, it is unclear how fast the intensification occurred during the 4-min period between scans. The circulation continues to strengthen through 2225 UTC, with gate-to-gate shear of 30 m s$^{-1}$ extending to 3 km AGL. One minute later, the tornado lifts off the ground, and at 2228 UTC, shear decreases at all levels above 1 km AGL. The circulation continues to weaken at 0.5 km AGL after 2234 UTC, providing strong evidence that the circulation has dissipated. However, the rate of dissipation cannot be determined from the available data.

The 1-min NWRT PAR data (Fig. 2) provide 17 volume scans during the analysis period. From these volumes, signs of circulation intensification first appear at 2217 UTC as gate-to-gate shear of 40 m s$^{-1}$ develops at 1.5 km AGL and immediately extends to 2.0 km AGL. The 40 m s$^{-1}$ shear then descends to 0.5 km AGL at 2219 UTC, providing evidence of circulation development up to 3 min before the tornado formed. At 2222 UTC, the shear further intensifies to 50 m s$^{-1}$ between 0.5–1.5 km AGL, just after the tornado is first observed. The circulation strength remains steady until the end of the tornado period (2225 UTC), when shear of 30 m s$^{-1}$ ascends to 3.0 km AGL. One minute later, the shear begins to weaken at all levels as the tornado lifts. Shear of 35 m s$^{-1}$ persists at 0.5 km AGL through 2227 UTC, then decreases within one min to 20 m s$^{-1}$. By 2230 UTC, shear is weaker than 20 m s$^{-1}$ at all levels, indicating that the tornado threat has diminished.

From these results, we find that simulated WSR-88D scans show the presence of a strong circulation, but the development and dissipation times cannot be determined from the data. Meanwhile, 1-min volumetric updates provide evidence of circulation development up to 3 min prior to tornado occurrence. Strong shear of 50 m $s^{-1}$ is observed just after 2221 UTC, providing further evidence that a tornado is likely. Evidence of weakening is seen aloft as gate-to-gate shear weakens just as the tornado dissipates at 2226 UTC. These signatures can provide the timely information required to determine whether a tornado is imminent, or whether the tornado threat is diminishing for a given location. This example indicates that the additional information from 1-min NWRT PAR scans may be very useful in improving the accuracy of warnings and special weather statements, especially when ground truth is not available to verify whether a tornado is on the ground.

## 3. METHODS FOR IMPROVING SAMPLING TIMES WITH PHASED-ARRAY RADAR

We have shown that 1-min updates provide more useful information for a particular tornadic storm than would have been observed using 4-min updates. However, improvements in scanning techniques now allow for volumetric scans in under 30 s (Heinselman et al. 2011). When using these techniques, extra time would be available to perform additional scans. How might we best use this surplus time to sample tornadic storms with a phased-array radar?

To better observe tornado development or dissipation, it is useful to provide focused low-level sampling only in areas of interest. The most focused sampling may be completed using a "mini-volume scan" which contains a limited number of elevations focused toward a desired region. If only two or four elevations are sampled in a mini-volume, several of these scans may be completed in a very short time. Thus, Interlacing several mini-volumes with a full 30-s volume scan can allow for rapid sampling of desired features while still fulfilling the 1-min requirement for sampling all locations. If storms are close to the radar (i.e., within 120 km), a uniform pulse repetition time (PRT) may be used to reduce scan times further and allow for additional interlaced mini-volumes. However, if second-trip echoes are possible, then a standard dual-PRT scan should be completed to ensure data quality is retained.

During the 2010 PARISE (Heinselman et al. 2011), the utility of a uniform PRT and interlaced mini-volumes were examined using a customized tornado scanning strategy. The strategy is based on a 22-elevation volume scan plus a series of four interlaced "mini-volumes" that are focused near the ground. A range oversampling technique is applied to all scans to maintain data quality while reducing scan times (Curtis and Torres 2011). In addition, several settings are available to account for target range from the radar. In this paper, we use a setting for targets only within 120 km of the radar, where four elevations were sampled in each mini-volume. All scans are completed using a single PRT, so volumetric updates were completed in 30 s while interlaced 4-tilt volumes were available in 8 s. The composite update time for all scans was 54 s, so the method satisfies the 1-min update requirement established by National Academies (2008).

## 4. USING RAPID UPDATES TO ANALYZE A STORM TRACK ON 10 MAY 2010

To analyze the potential benefits of the PARISE 2010 tornado scanning strategy, we examine a rapidly moving tornadic supercell sampled by NWRT PAR during the tornado outbreak of 10 May 2010. The tornado formed over southeast Moore, Oklahoma, and then moved northeast and produced EF4 damage and two fatalities near Interstate 40 in Choctaw, Oklahoma. On this day, storms were typically moving at speeds of 50–70 miles per hour (22.4–31.3 m $s^{-1}$). As such, this event provides an opportunity to examine how updates of 30 s or better might improve sampling of a fast-moving circulation. Due to hardware limitations, we were unable to sample the tornado's development within 10 km of the NWRT PAR. Hence, we focus on how the radar-estimated circulation track is affected by several update rates.

From the original NWRT PAR data with updates as fast as 8 s, we produce four separate data sets containing updates of 15, 30, 60 and 240 s, respectively. In each set, we identify the location of the circulation center using radial velocity from 2231–

2238 UTC, part of the period when the EF4 tornado was observed on the ground. We then compare circulation paths estimated from radial velocity to see how rapid updates affect the perceived circulation when using radar data. The true damage paths have not yet been evaluated in this study, so we have not yet compared the radar-derived tracks with the locations of actual storm damage. Instead, we use the radar-estimated tracks to determine whether an increased number of updates provides significantly more information when tracking circulations, especially before the damage path is known.

Since the storm was moving in excess of 50 miles per hour (22.4 m $s^{-1}$) , it traveled approximately 5.4 km during one 4-min volume scan. Thus, the 4-min NWRT PAR updates (Fig. 3) provide only a snapshot of the circulation's northeastward movement. This information may be sufficient to determine the general area where a tornado strikes, but it cannot provide more detailed information on specific locations that might have been damaged. When improving to 1-min updates (Fig. 4), it appears that the circulation associated with the tornado takes a northeastward track, but then jumps to the north between a meridional distance of 14–16 km. This track clearly shows that the circulation does not travel in a straight line but instead varies in direction. Furthermore, the 30 s updates (Fig. 5) show two sudden jumps to the north between a meridional distance of 12–16 km, and both occur within a minute of each other. These jumps in position may indicate the tornado momentarily lifted off the ground. A third northward jump is also observed far to the northeast, followed by a minute-long period of eastward movement. Given the trends in the overall storm path, the first two northward jumps appear plausible. However, it is unclear whether the third jump is realistic, since the single point deviates significantly from other points in the vicinity. It is possible that the circulation occupied multiple resolution volumes, leading to some uncertainties in the exact location of its center. To confirm the plausibility of the data, we examine the same trends using the 15-s updates (Fig. 6). In this case, the two northward jumps in the middle of the track appear more realistic, since several nearby points help improve our confidence that the track is consistent. The jump at the far northeast still seems to be a potential outlier, since no additional points appeared nearby when adding the 15-s updates.

From this analysis, we find that the 30- and 15-s updates show several fine scale details of the estimated circulation track that are not provided with 1-min updates. The two sudden jumps to the north provide additional evidence that the tornado may have briefly lifted off the ground or deviated significantly to the north. Although the 15-s updates do not provide a significant amount of new track information when compared to the 30-s updates, the 15-s updates did provide additional information which helped confirm two deviations in the circulation track and possibly identified a third deviation as an outlier. These details may provide additional information on where to best direct emergency crews immediately following the event, potentially reducing the number of lives lost due to delays in providing aid.

## 5. CONCLUSIONS

In this paper, we examined the effects of varying sampling times when using the NWRT PAR to observe two rapidly evolving tornado events. In the first event, we showed evolution of the gate-to-gate shear observed during a short-lived EF1 tornado that was observed on 07 May 2008. Here, the original 1-min NWRT PAR data were compared with a data set simulating WSR-88D VCP 12. From this comparison, we found that the native NWRT PAR data showed indications of circulation development 3 min before the tornado formed, while the simulated 4-min updates provided only 1-min of lead time. In this case, faster updates from NWRT PAR provide additional detail to better detect possible tornado development and dissipation. We also presented results from 10 May 2010, where a long-lived and fast-moving EF4 tornado was tracked using a series of four update intervals. We found that updates of 30-s showed several deviations in the tornado track that were not detected using 1-min updates, while 15-s updates provided additional temporal continuity which bolsters confidence that the track is accurate. These improved tracks could help National Weather Service personnel and emergency managers quickly determine locations where damage surveys and emergency services should be deployed following the tornado event.

Despite the positive results of this study, more case studies are needed to confirm that 30-s or faster updates are useful when sampling many different types of tornado cases. As opportunities arise, we will sample and evaluate additional tornado cases using the 2010 PARISE tornado strategy or another scanning strategy featuring rapid sampling. We will also consider other issues, such as how to balance scanning when multiple storm types are present. Such issues will need to be considered as scanning methods continue to be developed for a future Multifunction Phased-Array Radar system.

## 6. ACKNOWLEDGEMENTS

This research was supported by NOAA/Office of Oceanic and Atmospheric Research under NOAA–University of Oklahoma Cooperative Agreement NA17RJ1227 and Extension Agreement NA08OAR4320904. The authors thank Kevin Manross and Jennifer Newman for operating the NWRT PAR and obtaining valuable data during the two tornado cases.

## References

Bluestein, H. B., M. M. French, I. PopStefanija, R. T. Bluth, and J. B. Knorr, 2010: A mobile, phased-array Doppler radar for the study of severe convective storms: The MWR-05XP. *Bull. Amer. Meteor. Soc.*, **91**, 579–600.

Brown, R. A., V. T. Wood, R. M. Steadham, R. R. Lee, B. A. Flickinger, and D. Sirmans, 2005: New WSR-88D Volume Coverage Pattern 12: Results of field tests. *Wea. Forecasting*, **20**, 385–393.

Curtis, C. D. and S. M. Torres, 2011: Efficient range oversampling processing on the National Weather Radar Testbed. Preprints*, 27th Conference on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, Amer. Meteor. Soc., Seattle, WA, 13B.6.

Heinselman, P. L., D. L. Priegnitz, K. L. Manross, T. M. Smith, and R. W. Adams, 2008: Rapid sampling of severe storms by the National Weather Radar Testbed Phased Array Radar. *Wea. Forecasting*, **23**, 808–824.

Heinselman, P. L., S. M. Torres, D. LaDue, and H. Lazrus, 2011: 2010 Phased-Array Radar Innovative Sensing Experiment. Preprints*, 27th Conference on Interactive Information and Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, Amer. Meteor. Soc., Seattle, WA, 12B.4.

National Academies, 2008: Evaluation of the Multifunction Phased Array Radar planning process. Report prepared by the National Research Council, National Academy of Science, National Academy Press, 79 pp.

Ortega, K. L., T. M. Smith, K. L. Manross, K. A. Scharfenberg, A. Witt, A. G. Kolodziej, and J. J. Gourley, 2009: The Severe Hazards Analysis and Verification Experiment. *Bull. Amer. Meteor. Soc.*, **90**, 1519–1530.

Torres, S. M., R. Adams, C. Curtis, E. Forren, I. Ivic, D. Priegnitz, J. Thompson, and D. Warde, 2011: Software and signal processing upgrades for the National Weather Radar Testbed Phased-Array Radar. Preprints*, 27th Conference on Interactive Information Processing Systems (IIPS) for Meteorology, Oceanography, and Hydrology*, Amer. Meteor. Soc., Seattle, WA, 12B.3.

Zrnić, D. S., J. F. Kimpel, D. E. Forsyth, A. Shapiro, G. Crain, R. Ferek, J. Heimmer, W. Benner, T. J. McNellis, and R. J. Vogt, 2007: Agile-beam phased array radar for weather observations. *Bull. Amer. Meteor. Soc.*, **88**, 1753–1766.

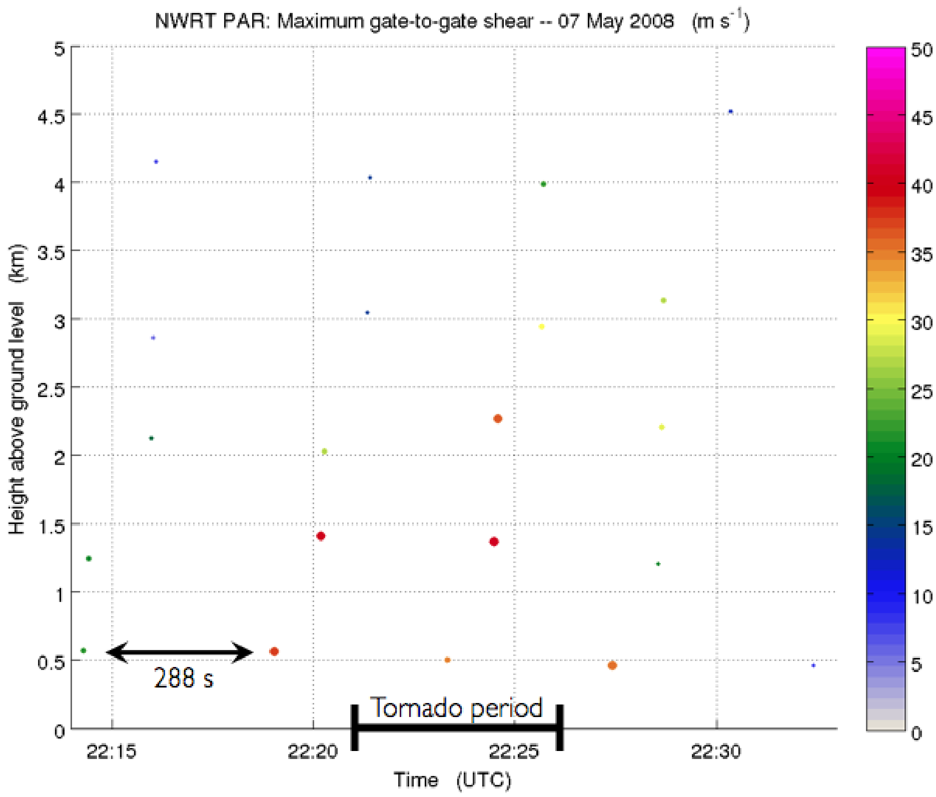


Figure 1. Time-height evolution of gate-to-gate shear during the 07 May 2008 EF-0 tornado. These points were measured using NWRT PAR data and a simulated VCP 12 scan time of approximately 4 min. Colors represent the magnitude of gate-to-gate shear measured from each elevation scan. The tornado was on the ground from 2221–2226 UTC.

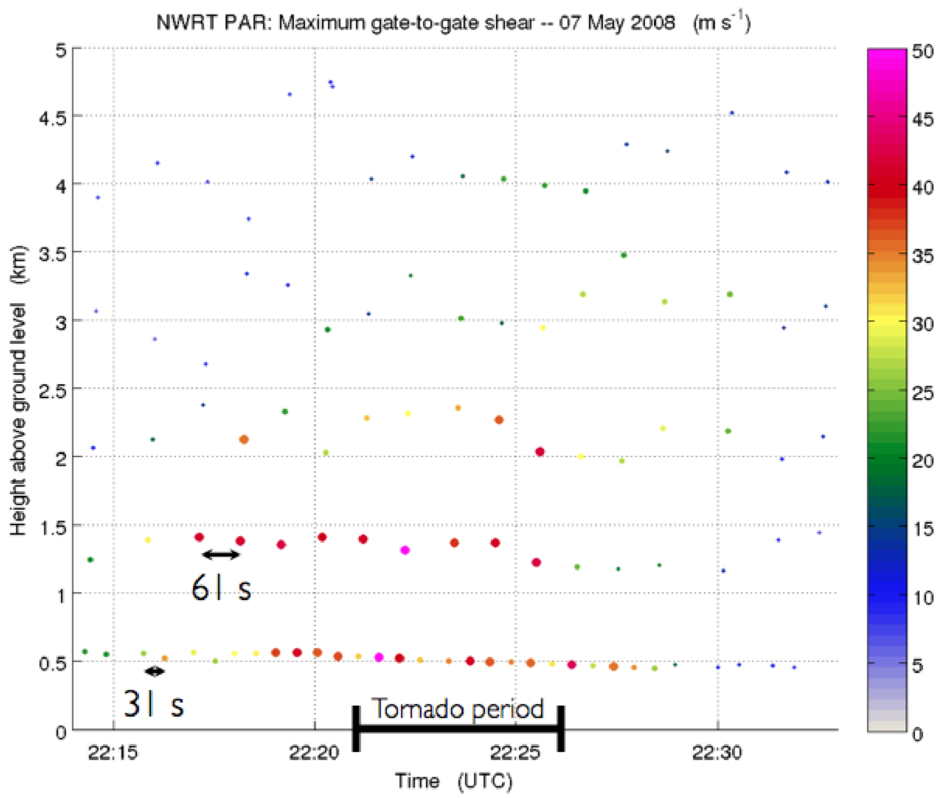


Figure 2. Same as Fig. 1, except showing native NWRT PAR resolution. The lowest elevation (0.5°) was sampled at a 30-s interval, while a complete volume was obtained in 60 s.

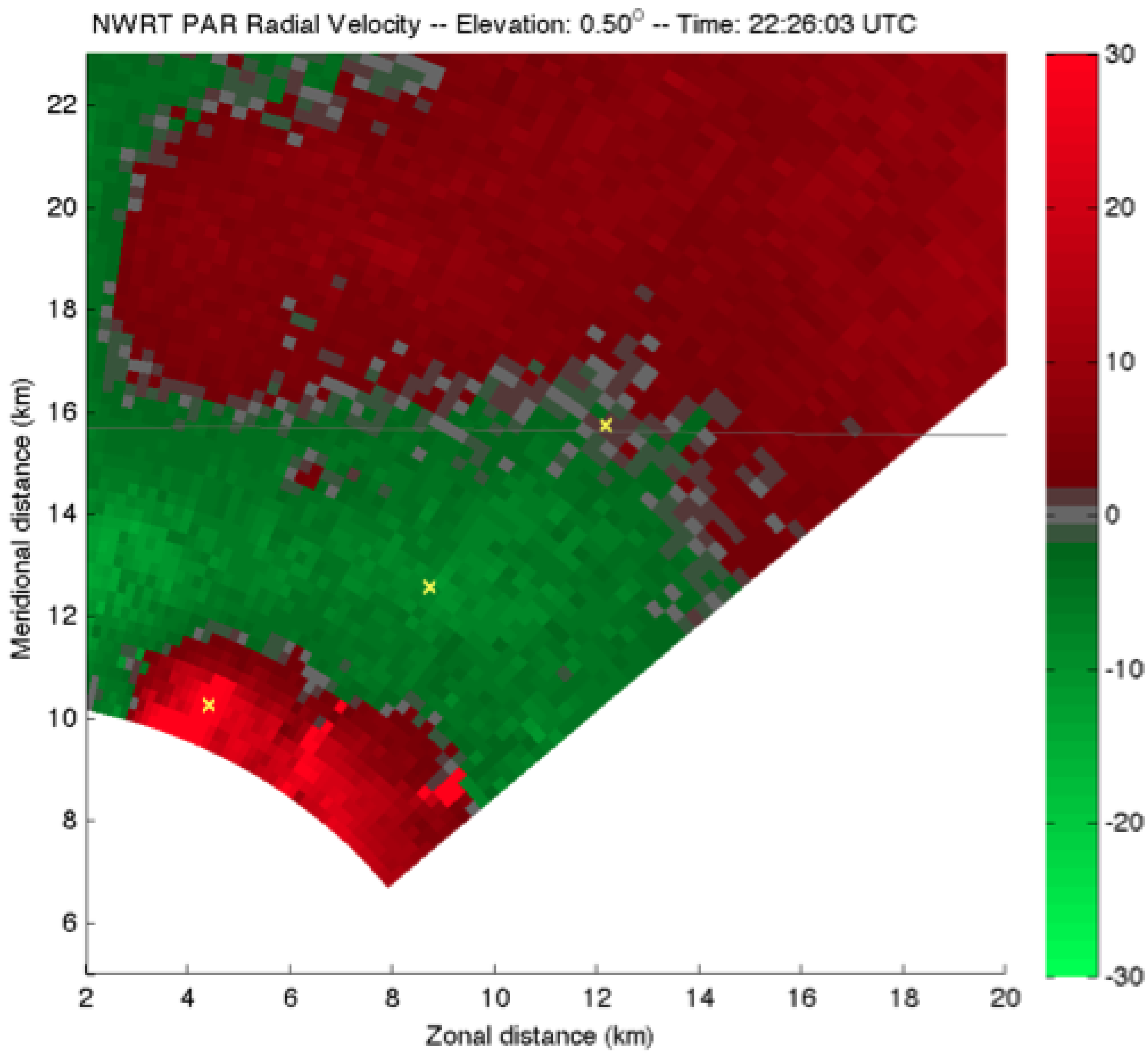


Figure 3. A circulation track obtained using NWRT PAR radial velocity from 2231–2238 UTC on 10 May 2010. The data was degraded to produce 4-min updates at the 0.5° elevation. Positions of the circulation center are indicated by yellow x's.

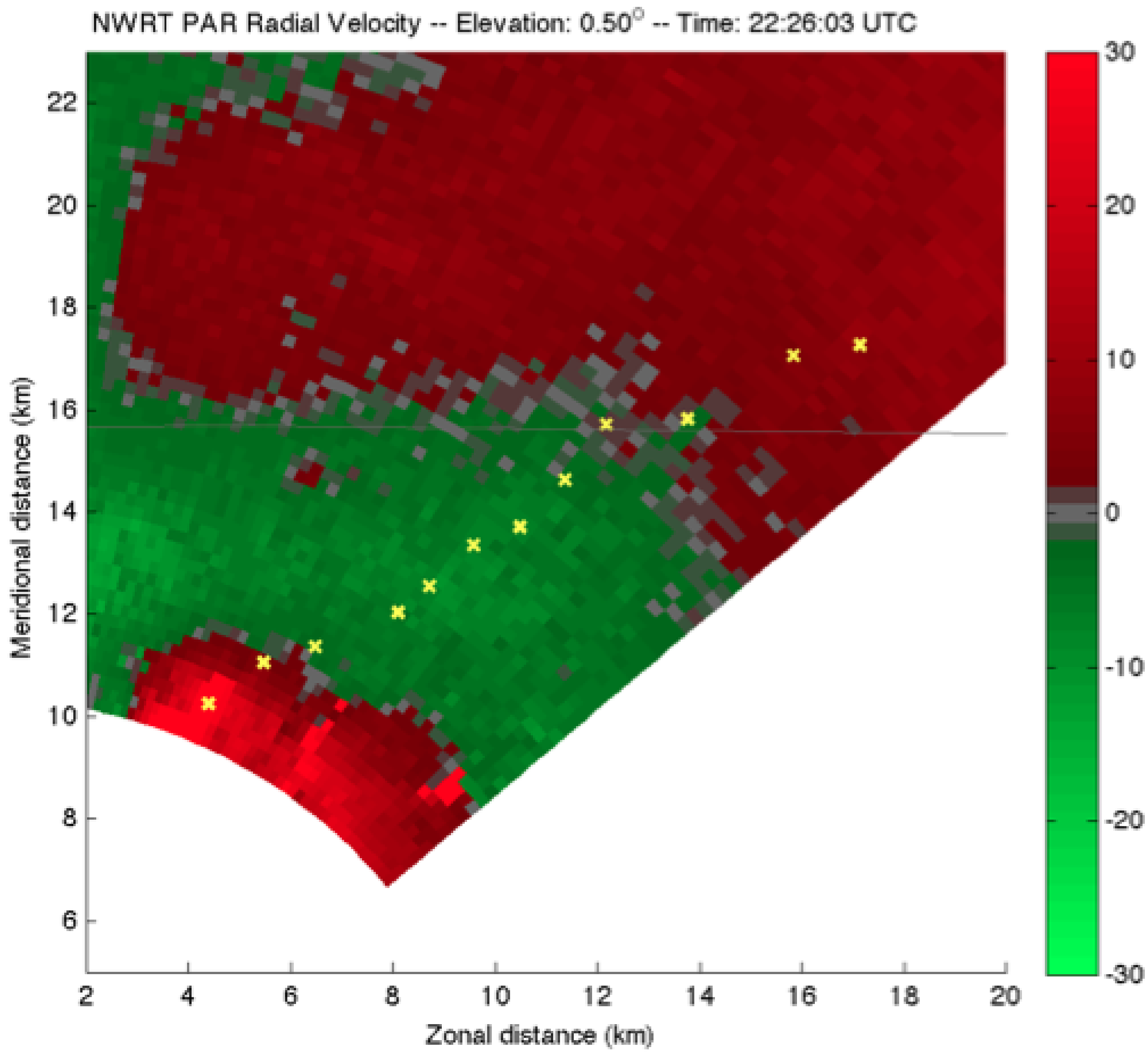


Figure 4. Same as Fig. 3, except showing the tornado path obtained using 1-min updates.

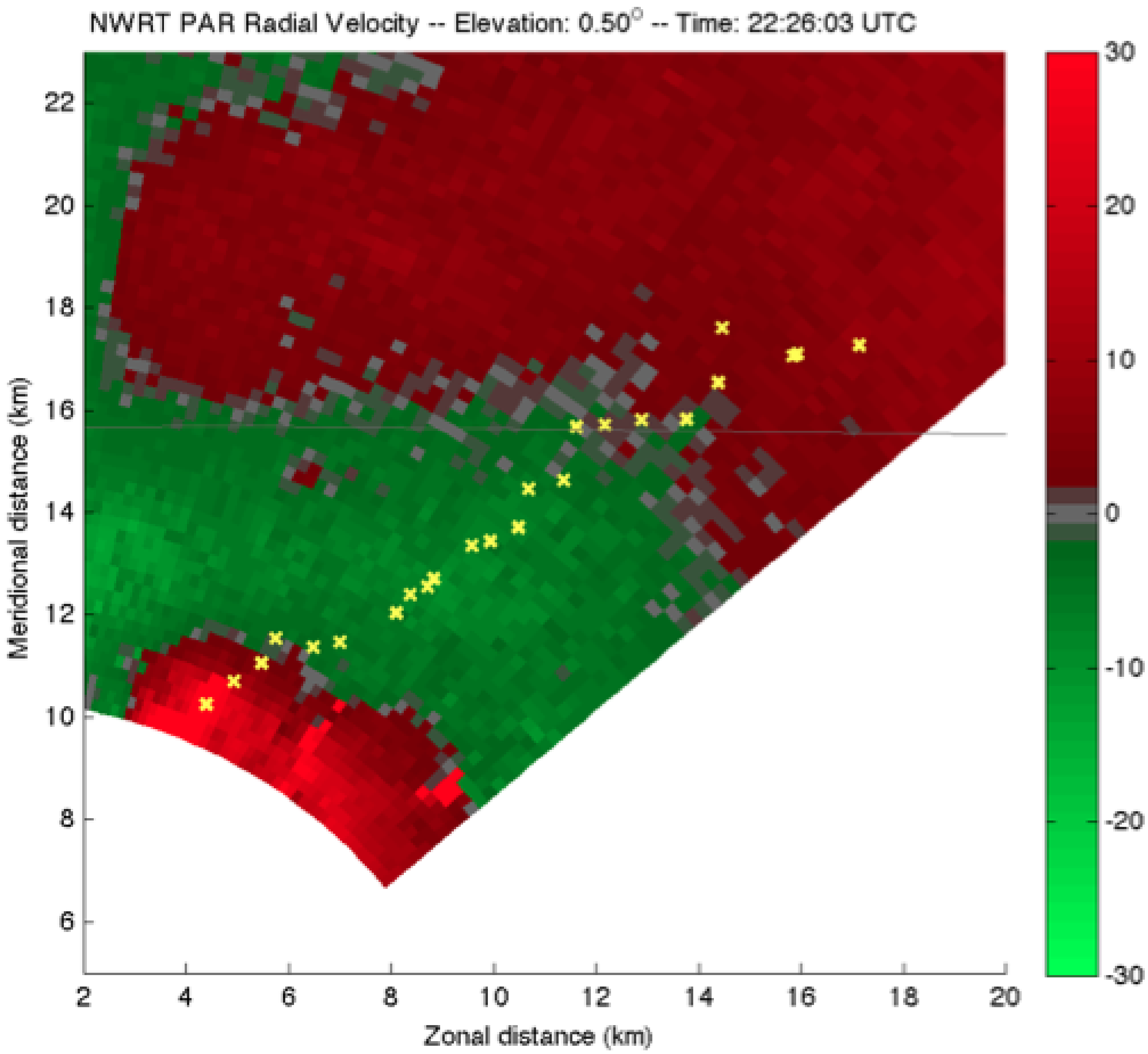


Figure 5. Same as Fig. 3, except showing the tornado path obtained using 30-s updates.

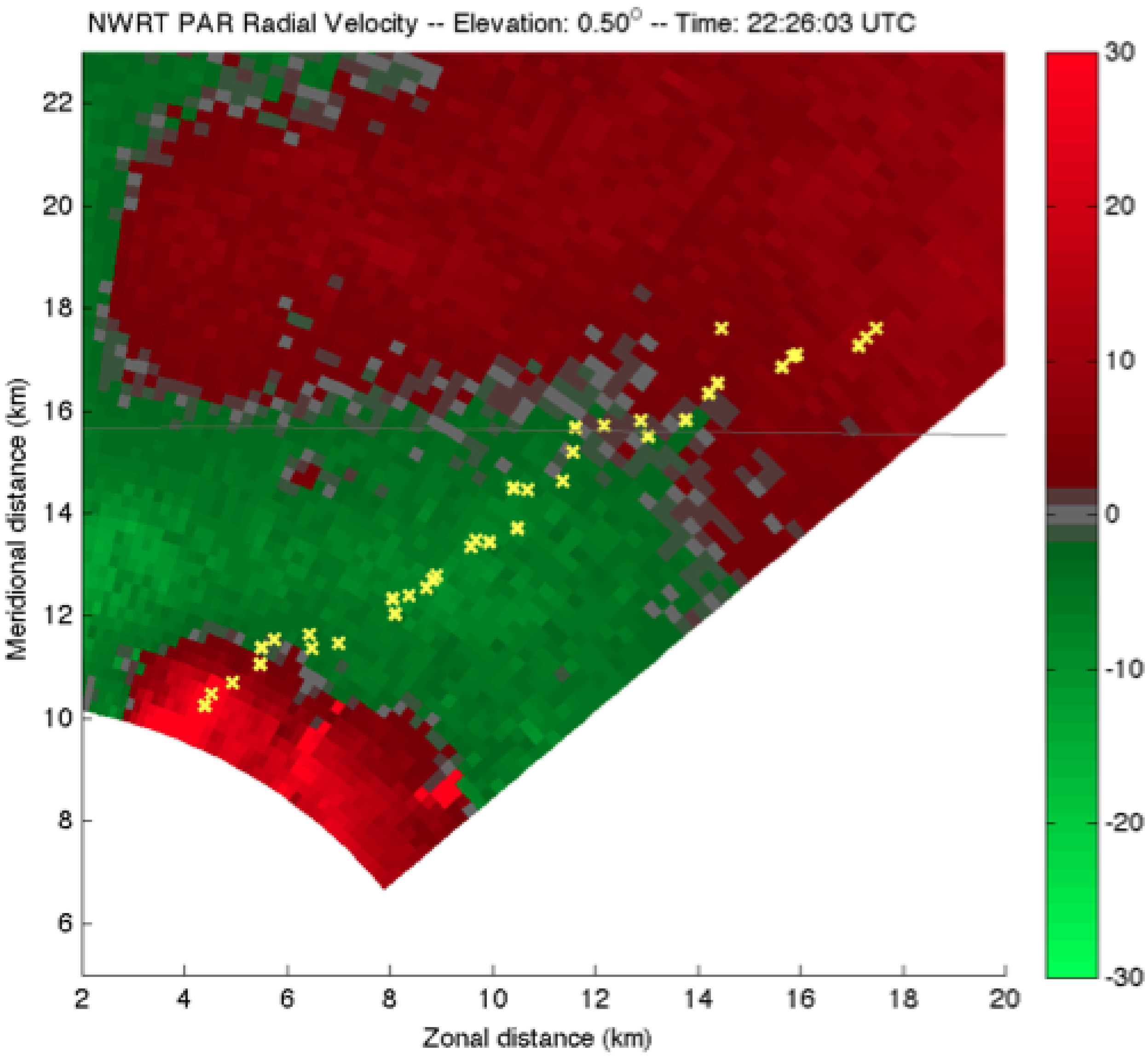


Figure 6. Same as Fig. 3, except showing the tornado path obtained using 15-s updates.