P147 DETECTION AND ADAPTIVE SCHEDULING ON THE NWRT PHASED-ARRAY RADAR

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1. INTRODUCTION

The positive benefits of faster scan updates in the detection and forecasting of severe weather have been well documented (Heinselman et al. 2012; Heinselman et al. 2013). Heinselman et al. (2008), using data from the National Weather Radar Testbed (NWRT) Phased-Array Radar (PAR), discussed the advantages of faster scan update times in capturing the evolution of three different types of severe weather. The rapid evolution of a hail storm was captured using a volume coverage pattern (VCP) with update times of ~26 s; a rate achieved by reducing data quality (shorter dwell times at each beam position). The evolution of a mesocyclone producing storm was captured using a VCP with comparable data quality to the WSR-88D VCP 12 but at an update time of ~58 s. The evolution of a microburst producing storm was captured with a similar VCP using a beam multiplexing technique to reduce update times to ~34 s. The study had the benefit of scanning an azimuthal sector of 90º, resulting in scan update times at least four times as fast as comparable WSR-88D scans. It is reasonable to assume the results could be applied to a fully functional, multiple-antenna, phased array radar capable of scanning a full 360º.

Heinselman and Torres (2011) discussed the tradeoffs between data quality and faster scan update times and demonstrated how adaptive scanning techniques developed for the NWRT PAR can be used to reduce scan update times while preserving data quality. Using the Adaptive Digital Signal Processing Algorithm for PAR Timely Scans (ADAPTS), significant improvements in scan updates could be achieved for isolated and distant storms without compromising data quality in active (precipitation) regions. Since the algorithm reduces scan times by sampling less frequently in inactive regions, it becomes less effective in situations of widespread precipitation or when echoes are close enough to the radar to be detected at the highest elevations.

From a forecaster perspective, one typically focuses their attention on the most dynamic regions within or near the most intense storms. It would then seem reasonable to focus scanning on those regions. Scanning would still be required to monitor development in the less significant regions but less frequently. Current operational rotating dish radars, like the WSR-88D, are not designed to selectively scan sectors encompassing storms. Doing so would not only require extra time for moving the antenna, it could also be harmful to the pedestal hardware. Phased-array antennas are ideally suited for sector scanning since beam steering is performed electronically. This paper extends the work by Heinselman and Torres (2011), presenting new adaptive scanning techniques developed for the NWRT PAR, with a goal of reducing scan times in the places that matter the most.

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2. ADAPTS UPGRADES

ADAPTS has gone through a series of three major evolutions to improve its effectiveness in reducing scan times. ADAPTS I executed a periodic full scan to detect new echoes in the regions not containing active weather (Heinselman and Torres 2011). ADAPTS II eliminated the periodic full scan by performing “surveillance” in the inactive regions of all scans (Torres et al. 2013). Surveillance was performed with a limited set of pulses (4) per beam position. The shorter dwell times in the surveillance regions resulted in faster scan updates. While data quality was reduced in the surveillance regions, it wasn't a major concern since the purpose of surveillance was to detect new echoes. Taking advantage of the fact that most weather VCPs used by the NWRT PAR over sample azimuthally by one half beam width, ADAPTS II was further modified to eliminate over sampling in the surveillance regions, reducing scan times even further.

The main difference between ADAPTS I and ADAPTS II is that surveillance in the inactive regions is performed more frequently with ADAPTS II; the periodic full scan in ADAPTS I served this purpose. However, in an active weather scenario, it would be more desirable to scan active regions more frequently and inactive regions less frequently, as was done with ADAPTS I.

A new version of ADAPTS, ADAPTS III, has been developed, combining the periodic full scan from ADAPTS I with the surveillance capabilities of ADAPTS II. This is accomplished by running a separate detection, or surveillance, scan. The detection scan replaces the periodic full scan from ADAPTS I using the surveillance properties of ADAPTS II. Like ADAPTS I, scanning is restricted to active regions in the weather VCP. Warde et al (2013) discuss the signal processing considerations used in supporting detection scanning at the NWRT PAR.

The detection scan is designed to provide full coverage inside a 90º azimuth and 60º elevation sector without beam overlap or gaps, reducing the number of beams by taking advantage of the wider beam away from bore site. The NWRT PAR transmitted beam width at bore site is ~1.5°, increasing to ~2.1° at an angle of 45° off bore site, resulting in a scan containing 55 azimuth beams at 36 elevations. The pulse repetition time (PRT) chosen for each elevation corresponds to the unambiguous range intersecting a height 18 km AGL, with minimum and maximum PRTs of 800µs and 3200µs, respectively. At 4 pulses per beam position, the detection scan takes ~7.5 s to complete. A beam map of the detection scan is presented in Fig. 1
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An advantage of using the detection scan is that it is VCP independent. Since there are no gaps in coverage, all beams in a VCP can be mapped to a detection beam. Most operational weather VCPs and those used by the NWRT PAR have gaps between higher elevation cuts.

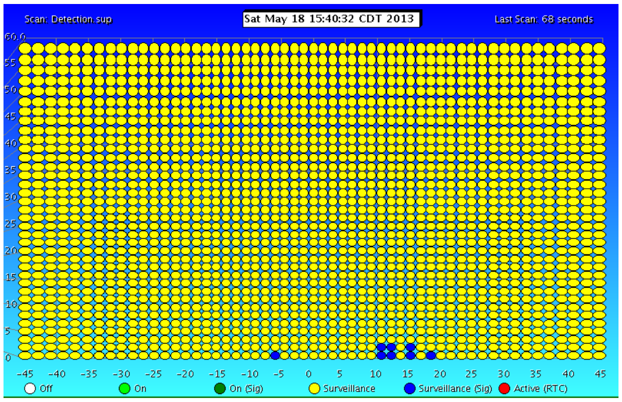

Fig. 1. A snapshot of the beam map used by the detection scan on May 18, 2013 at 15:40:32 CDT. Yellow circles indicate surveillance beams not containing significant weather. Blue circles indicate surveillance beams containing significant weather.

New echo development in these gaps can be detected earlier by the detection scan allowing beams in nearby elevations to be activated sooner in the weather VCPs.

The overall time savings from running periodic detection scans are greatest when storms are isolated and distant from the radar. When storms are widespread and close to the radar, the time required to do periodic detection scans could be larger than the time saved by turning off inactive beams in the weather VCP. In this situation it would be better not to have ADAPTS III active.

3. SCAN PROCESSING

The new adaptive scanning techniques being developed for the NWRT PAR have required a more flexible and robust scheme for scheduling VCPs. The software was originally designed to support a single VCP which couldn't be changed during active scanning. Several years ago, a scan table control scheme was implemented in the NWRT PAR software, allowing up to 10 different VCPs to be scheduled and run (Priegnitz et al. 2007).

Scan table processing is performed in a round-robin fashion starting with the first VCP entry in the table. Individual VCP entries can be repeated a specific number of times or repeated until a specified amount of time has elapsed. The scan table itself can be repeated. The VCPs can be changed or modified while scanning is active.

The VCPs used by the NWRT are created offline and saved as files. An operator loads the VCPs into the scan table using the Radar Control Interface (RCI) client (Priegnitz 2009). A scan table can be saved for later reference and/or sent to the Real Time Controller (RTC) to be loaded for execution. The RTC controls the NWRT PAR pedestal, antenna, transmitter, and receiver hardware. When the RTC receives a start scan command from an RCI client, it translates the VCP definition into a set of commands which, beginning with the first VCP in the scan table, are sent to the aforementioned radar components. The commands are stored in a command buffer and reused as long as the VCP doesn't change. A scan is guaranteed to contain a start of volume (first pulse) and an end of volume (last pulse) indicator, whether or not the scan was completed or aborted. If a VCP is replaced or modified while scanning is active, the command buffer will be rebuilt prior to running it again.

When ADAPTS is enabled, scan processing is affected in several ways. When scanning is started, a detection scan is run first. After that, a detection scan will interrupt scan processing after a specified amount of time has elapsed. The detection scan will not interrupt an active VCP. It will run after the active VCP completes and before the next VCP starts. At the digital signal processor (DSP) component, ADAPTS maintains a beam table referenced by azimuth and elevation. After all beams in an elevation are updated, the DSP software sends an ADAPTS elevation beam map message to the RTC. The message contains an action code for each azimuth position in the elevation. An action code specifies whether a beam is active or inactive. During scan processing, commands in the command buffer associated with inactive beams are skipped.

4. ADAPTIVE SCHEDULING

As mentioned earlier, forecasters tend to focus their attention on the most intense weather, something that ADAPTS does not do. From a scanning perspective, it would be desirable to scan sectors containing the most intense storms more frequently than sectors that don't. To do this, one would first need to identify the storms. Next, VCPs would need to be created and scheduled to focus on the sectors containing the storms. Attempting to do this manually in an operational environment would be difficult to impossible. This process would be time consuming and have to be repeated to account for changes in storm structure and movement.

Priegnitz et al. (2012) developed a weather tracking algorithm (WTA) to track a single user defined weather feature at the NWRT PAR. The purpose of the algorithm was to keep the weather feature inside the field of view of the antenna. However, it does not take into account changes in storm size; something that would be required for a focused storm scan.

Priegnitz et al. (2013) describe a cluster identification algorithm (CIA) that uses a technique described by Lakshmanan et al. (2009) to organize the low elevation reflectivity field into a set of objects, or "clusters"(Figs. 2A and 2B). Unlike WTA, CIA does take into account changes in cluster size which makes it suitable for defining the sector properties required for a focused storm scan. However, CIA does not track clusters from scan to scan. Priegnitz et al. (2013) described how CIA and WTA could be used together to track an algorithm identified cluster, or storm.

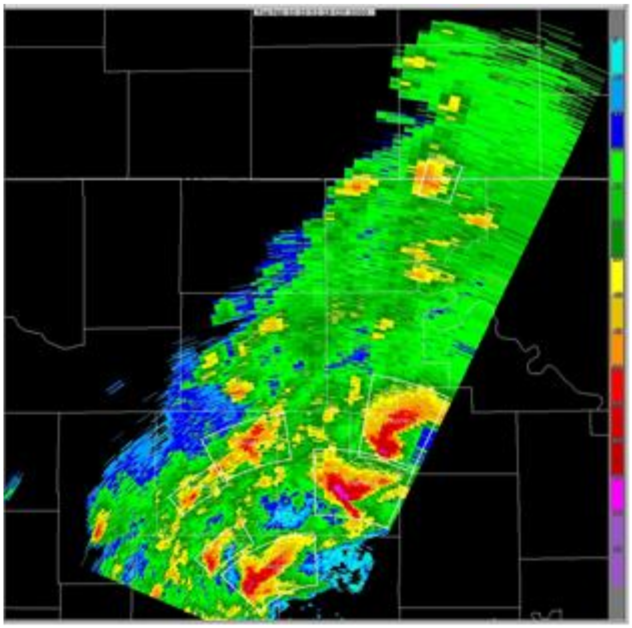

Fig. 2A. 0.5º elevation reflectivity display at 15:58:12 CDT on 10 Feb 2009.

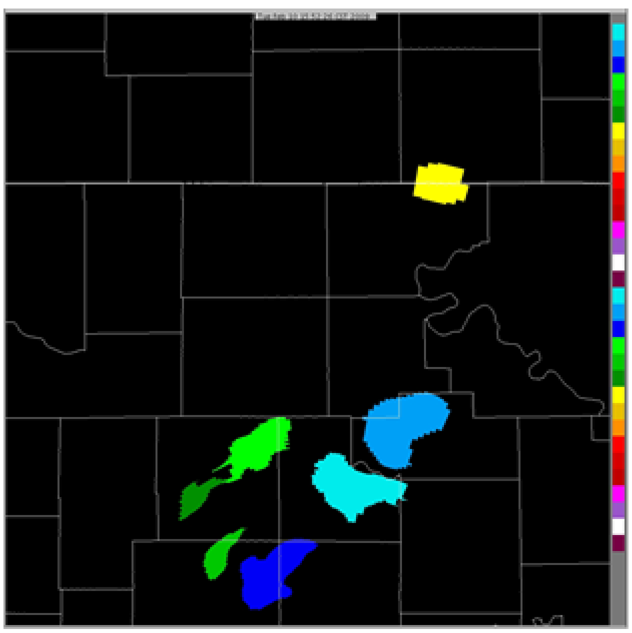

Fig. 2B. Cluster display for 15:58:12 CDT on 10 Feb 2009.

To support focused storm scanning at the NWRT PAR, software changes have been made that allow more frequent updates in the sector surrounding an operator selected cluster. The process begins with identifying a cluster. Using the RCI client, an operator selects a storm of interest from a base reflectivity product. Output from CIA is then searched for a cluster that contains the selected location. If a match is found, the operator activates tracking and scheduling for the selected storm. At the RCI server, a copy of the primary VCP is retrieved from the first position of the scan table and edited. The sector properties are modified to focus on the region containing the cluster. The new "cluster" VCP is sent to the RTC where it is inserted into the scan table.

When scanning is started the primary VCP is executed first followed by the cluster VCP. When the cluster VCP is started a timer is activated. The cluster VCP is repeated until the timer expires. By default the timer is set to 60 s. This value can be changed by an operator prior to activating tracking and scheduling at the RCI client. The CIA does not process data from the cluster VCP, only the primary VCP. Whenever the primary VCP is run, new cluster information is received from the CIA after the lowest elevation has completed. The sector properties of the cluster VCP is updated and sent to the RTC so it can be applied the next time the cluster VCP is run. The cluster VCP is removed from the scan table whenever tracking or scheduling is deactivated.

Fig. 3 shows a typical RCI client scan panel display containing primary and cluster VCPs. The top half of the scan panel contains a tabular listing of the VCPs contained in the scan table along with some selected properties. In this example, the primary VCP in slot 1 will require ~68 s and the cluster VCP in slot 2 will require ~13 s to complete (when ADAPTS is inactive). Using a 60 second timer, the cluster VCP would repeat 5 times for every one primary VCP. Note the two VCPs at the bottom of the scan table. The VCP loaded in slot 11 is used by ADAPTS for the detection scan. The VCP loaded in slot 12 is used for aircraft tracking and will be part of the NWRT PAR multifunction demonstration in the fall of 2013. It is inactive by default. They exist in all scan tables and cannot be modified by the operator. The bottom half of the scan panel shows a graphical display of the beams defined by a selected VCP. In this example the beam map for the primary VCP is displayed. The beams are color coded to indicate waveform type.

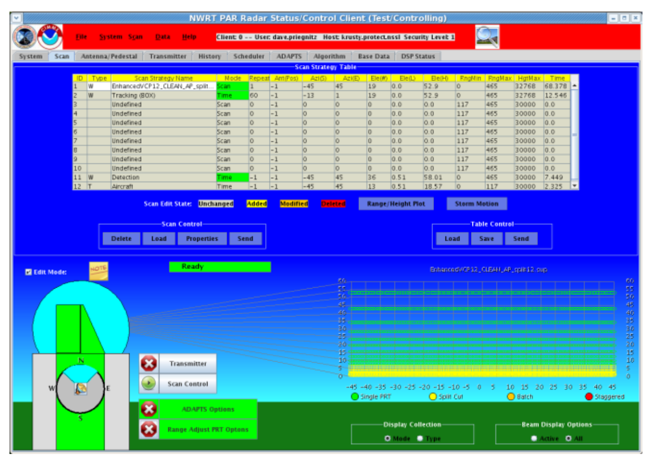

Fig. 3. Snapshot of an RCI client Scan Panel.

5. 18 MAY 2013 TEST CASE

On 18 May 2013 a large region in western Oklahoma experienced severe storms which produced large and damaging hail. As the storms moved into central Oklahoma, a single storm was selected and scanned more frequently than the others. Several figures are presented that illustrates a typical identification, selection, and scheduling process.

A PPI display of the 0.5º reflectivity field at 17:48:21 CDT and the corresponding cluster analysis produced by CIA are shown in Figs. 4A and 4B. For display purposes, clusters are color-coded and tagged with labels that rank them based on maximum reflectivity. The light blue cluster, “Cluster 1”, is the highest ranked cluster, the medium blue cluster, “Cluster 2”, is the next highest ranked cluster, and so forth. The white boxes drawn around each cluster show their azimuth-range extents. The cluster analysis did a reasonable job of identifying 8 clusters, or storms. In our test the highest ranked cluster, “Cluster 1”, was selected and a new scan, focusing on the sector containing it, was scheduled.

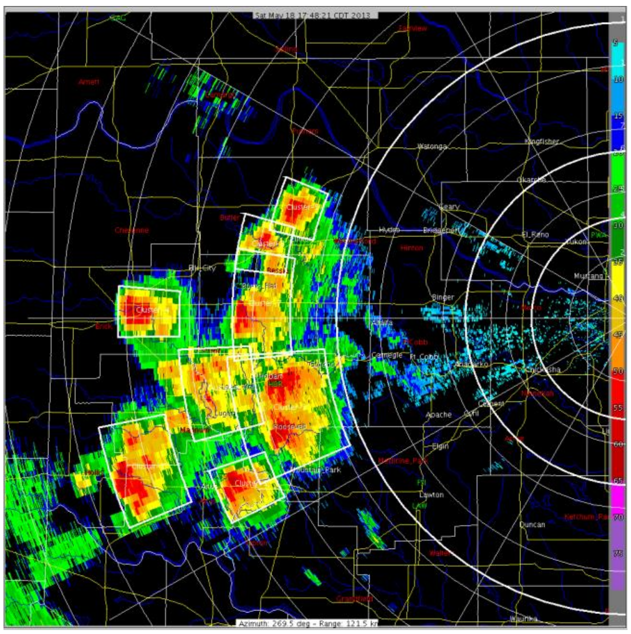

Fig. 4A. 0.5º elevation reflectivity display for 17:48:21 CDT on 18 May 2013.

Fig. 5A shows the beam map produced by ADAPTS for the primary VCP at the time the cluster VCP was scheduled. Fig. 5B shows the beam map produced by ADAPTS for the cluster VCP a short time later. The green circles represent active beams and white circles inactive beams. The primary VCP scanned a 90º azimuth sector containing 109 beams per elevation. The cluster VCP scanned an ~8º azimuth sector containing 11 beams per elevation. By running ADAPTS, scan the update time for the primary VCP was reduced from ~68 s to ~53 s; a saving of ~15 s. For the cluster VCP, ADAPTS reduced the scan time from ~7 s to ~6 s; a savings of ~ 1 second. Using a timer of 60 s, the cluster VCP was repeated 10 times before the full primary scan was run again.

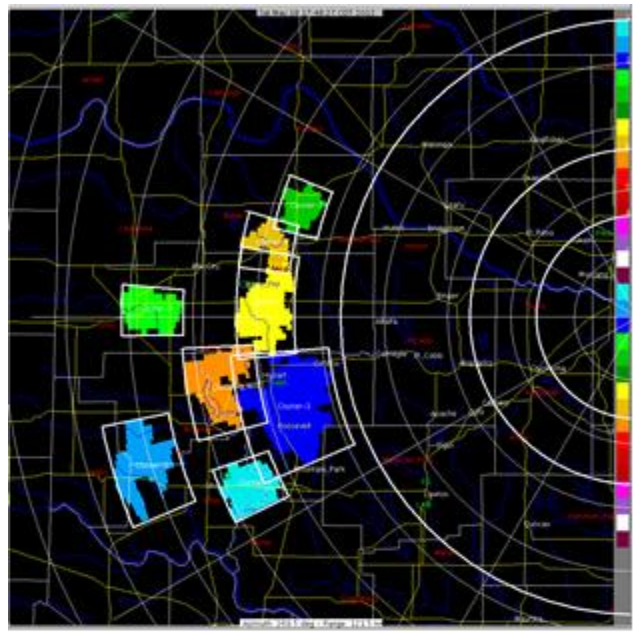

Fig 4B. 0.5º elevation cluster display for 17:48:21 CDT on 18 May 2013.

A PPI display of the 0.5º reflectivity field at 17:50:33 CDT, showing the focused cluster scanning, is shown in Fig. 6. Although not shown here, the RCI client provides a display option to integrate data from both the primary and cluster scans into a single product. This way one does not lose track of what is occurring outside the cluster sector. However, one needs to remain cognizant of potential discontinuities at the transitional beams from the cluster scan to the primary scan.

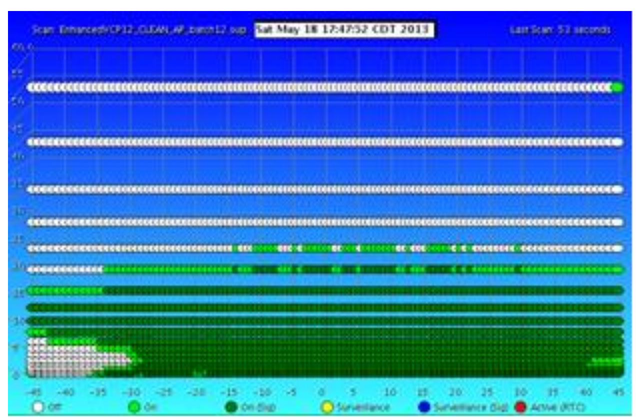

Fig 5A. ADAPTS beam map display at 17:47:52 CDT on 18 May 2013.

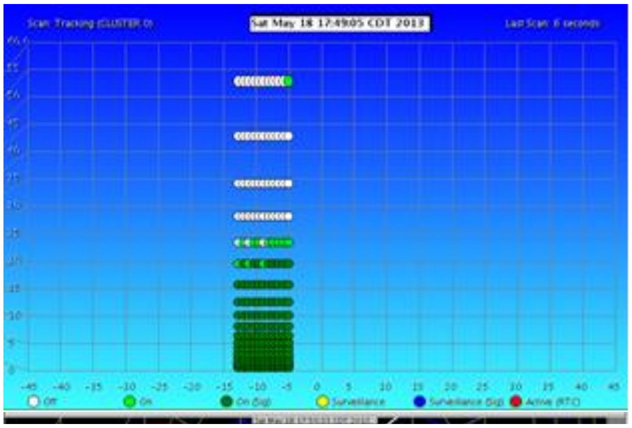

Fig 5B. ADAPTS beam map display at 17:49:05 CDT on 18 May 2013.

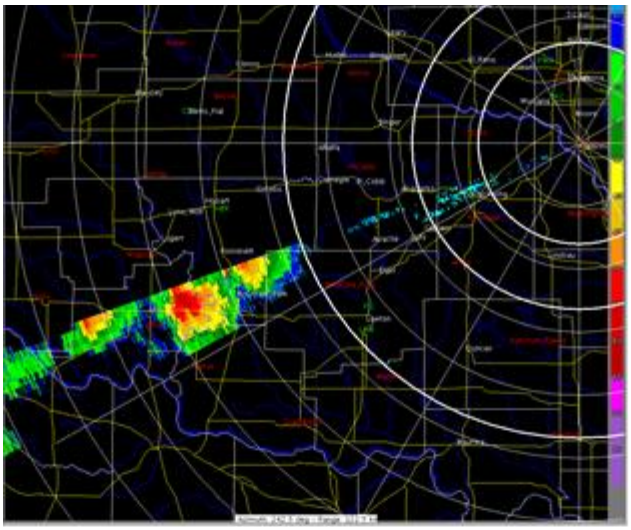

Fig 6. 0.5ºg reflectivity display at 17:50:33 CDT on 18 May 2013.

6. SUMMARY

A new storm detection, identification, tracking, and scheduling scheme has been implemented at the NWRT PAR to support focused scanning of individual storms. Early testing has demonstrated the potential benefits for forecasters wanting more frequent scan updates in regions containing the most intense weather but still providing less frequent updates elsewhere. The continued evolution of ADAPTS has resulted in better detection and faster scan updates for isolated and distant storms. However, the need for faster updates is the same regardless of coverage and proximity of storms to the radar. The scheme presented here, when used with ADAPTS, can be used to improve scan update times when and where it matters the most.

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