P11 Adaptive Multiple Storm-based Scanning at the National Weather Radar Testbed Phased Array Radar

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1. INTRODUCTION

The electronic beam steering ability of phased array antennas allow more creative scanning of severe weather than conventional rotating dish antennas. Operational dish antennas typically rotate continuously in one azimuth direction, changing elevation angles after a full 360 sweep has completed. After completing a full volume coverage pattern (VCP), the antenna is returned to the beginning elevation angle (typically lowest) and the process repeated. As the antenna rotates, no distinction is made between beams containing and not containing precipitation.

The capability to identify and scan only regions containing precipitation has been demonstrated using the Adaptive Signal Processing Algorithm for PAR Timely Scans (ADAPTS) at the National Weather Radar Testbed (NWRT) Phased Array Radar (PAR) (Heinselman and Torres 2011). A positive benefit of ADAPTS is to reduce scan update times leading to improved detection and forecasting of severe weather (Heinselman et al. 2008, 2012). However, scan update times are inversely proportional to precipitation coverage; as precipitation becomes more widespread within the field of view of the antenna, the benefit decreases.

As a general rule, forecasters tend to focus their attention on the most intense weather. Therefore, it is advantageous to focus scanning on those regions. Priegnitz and Heinselman (2013) describe an algorithm which has been used by the NWRT PAR to identify storm clusters from reflectivity data and to define sectors for focused scanning. By utilizing minimum and maximum reflectivity thresholds, the stronger-convective elements can be separated from the less intense or stratiform regions. The sectors encompassing these storm clusters can be used for focused scanning.

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Until recently, focused scanning at the NWRT PAR had been limited to a single operator-selected storm cluster sector. In many situations, multiple candidate storm clusters exist within the coverage area. Modifications have been made to the NWRT PAR software to support scanning of multiple storm cluster sectors. This paper describes the storm cluster selection and scheduling process along with a recent example.

2. ADAPTIVE SCANNING PROCESS

Since becoming operational in 2004, the NWRT PAR software has gone through a progression of improvements (Torres at al 2012, 2013). The first improvements focused on operability and data quality. More recent improvements have focused on multi-function and adaptive scanning.

A functional flow diagram of the adaptive scanning process is presented in Fig 1. The NWRT PAR software can be broken up into three functional groups: Radar Control Interface (RCI), Real Time Controller (RTC) and Environmental Processor (EP). The RCI serves as the main control component, accepting commands from a human operator and directing them to the other components. The RCI consists of a single server and one or more client applications. The server acts as a collector of status and product data and passes them to clients on demand. The RTC interfaces with the radar hardware and maintains a scan table which can be executed on command. During a scan, time series data are sent from the RTC to the EP where it is processed into spectral moments, removing non-meteorological information in the process. The “clean” spectral moment data are then processed by additional algorithms such as, Product Generator, Cluster Identification, ADAPTS, Cluster Tracking and Weather (Wx), which are part of the adaptive scanning process.

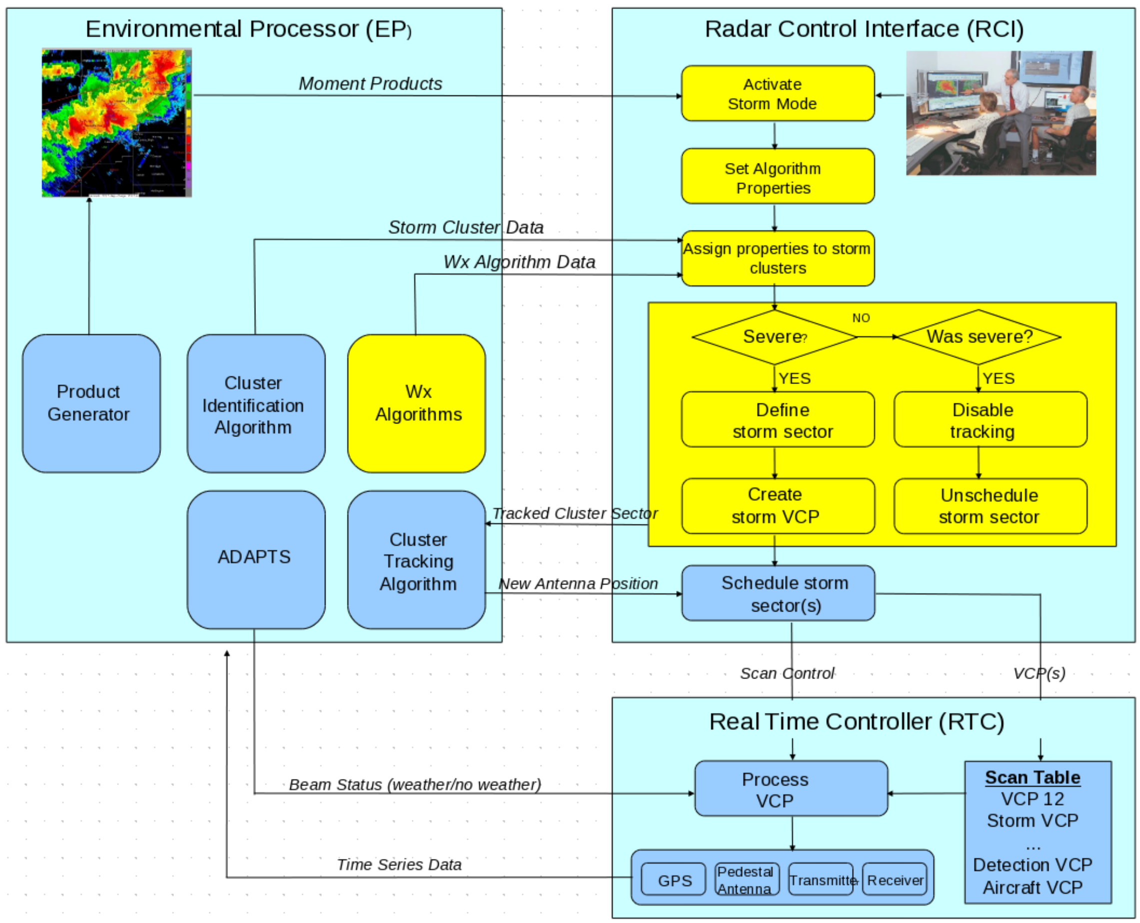

Fig. 1. A functional diagram of the adaptive scanning process at the NWRT PAR.

When adaptive scanning is initiated, base moment products (reflectivity and radial velocity) are generated by the Product Generator Algorithm and sent to the RCI server. These products are then sent by request to RCI clients for display. Storm cluster properties, identified by the Cluster Identification Algorithm, are also sent to the RCI server and passed to RCI clients on request. Storm cluster properties include the bounding azimuth angles which are used to define the sector for focused scanning. A storm cluster can be selected by the operator and scheduled for focused scanning as long as it has been identified by the Cluster Identification Algorithm. The range of the storm cluster gate with the highest reflectivity is used by an algorithm at the RCI server to create a storm sector VCP, providing a vertical resolution between elevation cuts of 0.5 to 1.0 km (Priegnitz et al 2014). This information is then passed to the RTC where it is added to the scan table and converted into a command list prior to execution.

The scan table contains slots for up to 10 weather VCPs. During focused storm sector scanning, the first slot is reserved for a predefined general VCP (i.e., VCP 12) and the rest for focused storm sector scanning. The general VCP uses a "one size fits all" set of elevations covering the full azimuthal view of the antenna (90º). Beams in the general and storm sector VCPs are overlapped in azimuth by one half beamwidth.

Scanning is performed in a round robin fashion starting with the general VCP. If ADAPTS is active, a special fast surveillance, or detection scan, using a set of non-overlapping beams covering the entire field of view (+/- 45° azimuth; 0.5°-60° elevation), is executed first and then repeated in regular intervals (typically every ~2 minutes). The detection scan uses a limited number of pulses (4) per non-overlapping beam position to quickly scan the full sector (less than 8 seconds). Its purpose is to identify regions containing precipitation. This information is used by the scan control software to control where to scan in other VCPs.

Upon completion of the general VCP a “storm” timer is started. The focused storm sector VCPs are executed and repeated until the storm timer expires, at which time the general VCP is repeated. The scanning of general and storm sector VCPs are interrupted by a detection scan whenever the detection timer expires.

New storm cluster properties are generated whenever a new general VCP is executed. When the RCI server receives the new cluster properties it attempts to match any existing active storm cluster (one that had been previously selected by the operator) with a new storm cluster. If a match is found, an updated storm VCP is created and sent to the RTC. If a match is not found and the active storm cluster was previously targeted for focused scanning, it is removed from the selected storm list and scan table.

3. AUGUST 18, 2015 EVENT

On August 18, 2015, a weak cold front was the focus for late afternoon deep convection in west central Oklahoma, providing an opportunity to use the NWRT PAR to focus scanning in multiple storm sectors. The cluster identification algorithm was set up to use a reconstructed reflectivity profile at 7 km MSL (CAPPI) as input. Gates with filtered reflectivities less than 35 dBZ were not considered in the cluster analysis. To be considered, a storm cluster was required to contain at least one gate with a maximum reflectivity greater than 50 dBZ and cover an area of at least 16 km^2. Using these criteria, two storm clusters were identified and selected for focused scanning.

For this event the amount of time allocated for focused storm scanning was set to 2 minutes. During this time, two storm sector VCPs were executed in a round-robin fashion. Each storm sector VCP was allocated a minimum of 5 seconds of scan time per cycle and if completed in less time than this the VCP was repeated until this time was reached or

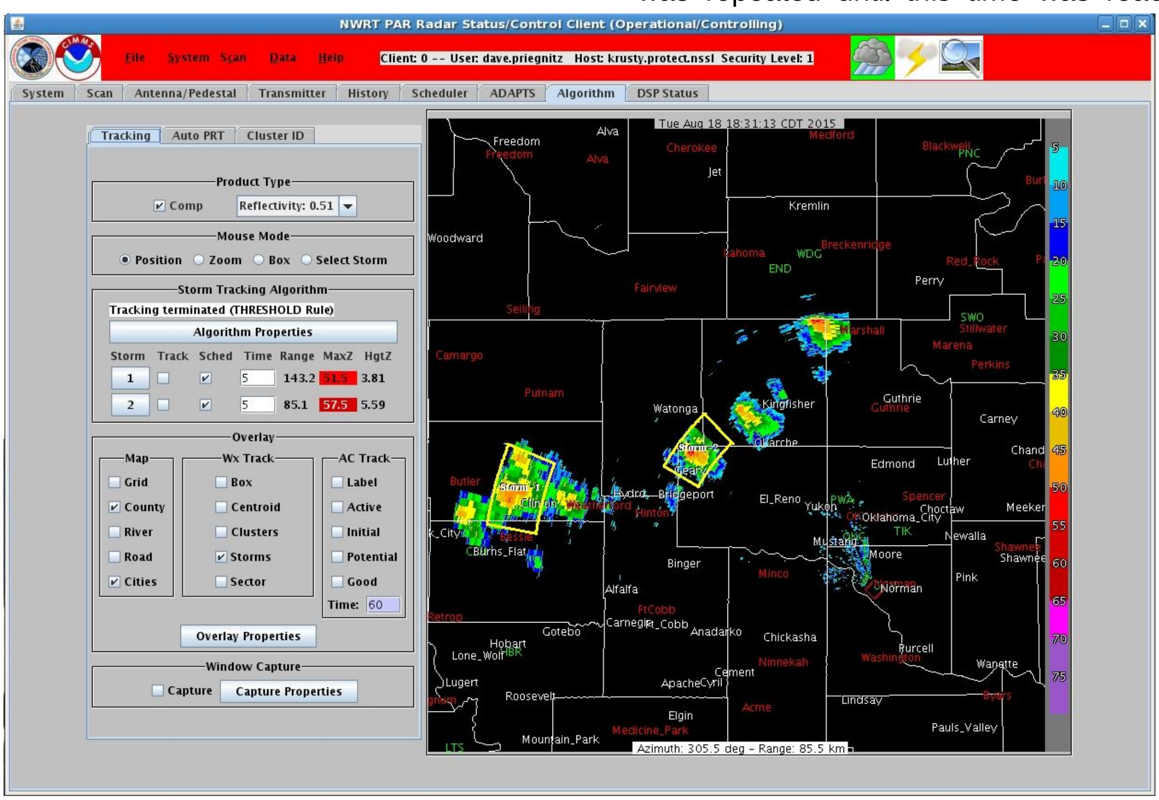

Fig. 2: RCI client algorithm display window containing 0.5° PPI reflectivity display with storm boxes overlaid.

exceeded. In addition, ADAPTS was active and an independent detection scan was run every ~2 minutes. After completion of a general or storm sector VCP the detection timer was checked. When the timer reached or exceeded 2 minutes, a detection scan was executed.

An RCI client display showing 0.5° reflectivities at 13:31:13 UTC is presented in Fig. 2. The two yellow boxes encompassing the two storms reflect their azimuth and range boundaries as defined by the cluster identification algorithm. A 4-km adjustment factor was applied to the left and right sector azimuths to widen the scan sector. Since cluster identification focused on higher reflectivity cores, it was important to widen the scan sector to capture more of the storm structure and environment around them.

To the left of the reflectivity display is a table showing the range, value, and height of the maximum reflectivity gate for each storm cluster. In this example, the values were 143.2 km range, 51.5 dBZ, and 3.81 km MSL for storm 1 and 85.1 km range, 57.5 dBZ, and 5.59 km MSL for storm 2. The “Track” and “Sched” check boxes indicated whether a selected storm was tracked (kept within the antenna field of view) and/or the sector containing it was scheduled for focused scanning. In this example, since both storm clusters were scheduled, range-based VCPs were created for each storm cluster sector and added to the scan table.

To illustrate how VCPs were executed, a small time segment of scan table processing is presented in Table 1. When scanning was first initiated, a detection scan was followed by a general (Enhanced VCP 12) and two storm sector VCPs. The storm sector VCPs repeated until after the fifth iteration when another detection scan was run (the detection timer was greater than 2 minutes). After three more pairs of storm sector VCPs were completed another general VCP was started (the storm timer was greater than 2 minutes). The ADAPTS significantly reduced the general VCP scan time from ~68 seconds down to ~38 seconds and provided minimal time savings for the storm sector scans.

ADAPTS generates a real-time beam map which is updated and sent to the RCI server. The RCI client uses this information to create a graphical display of the full beam map for all active VCPs. Beam map displays from 13:31:13 UTC for the detection, general, and storm sector VCPs are shown in Figs. 3-5.

VCP	Volume Time (s)	Detection Timer (s)	Storm Timer (s)	Elapsed Time (s)
Detection	8	0	0	0
Enhanced VCP 12	38	8	0	8
Storm 1	6	46	0	46
Storm 2	9	55	6	55
Storm 1	6	61	15	61
Storm 2	9	67	21	67
Storm 1	6	76	30	76
Storm 2	9	82	36	82
Storm 1	6	91	45	91
Storm 2	9	97	51	97
Storm 1	6	106	60	106
Storm 2	9	112	66	112
Detection	8	121	75	121
Storm 1	6	8	83	129
Storm 2	9	14	89	135
Storm 1	6	23	96	144
Storm 2	9	29	102	150
Storm 1	6	38	111	159
Storm 2	9	44	117	165
Enhanced VCP 12	38	53	126	174
Storm 1	6	91	0	212
Storm 2	9	97	6	218

Table 1: Sample scan sequence during storm mode with two active storm sectors and ADAPTS active. The detection and focused scanning timers were each set to 2 minutes. The timer and elapsed times are at the start of scan volume.

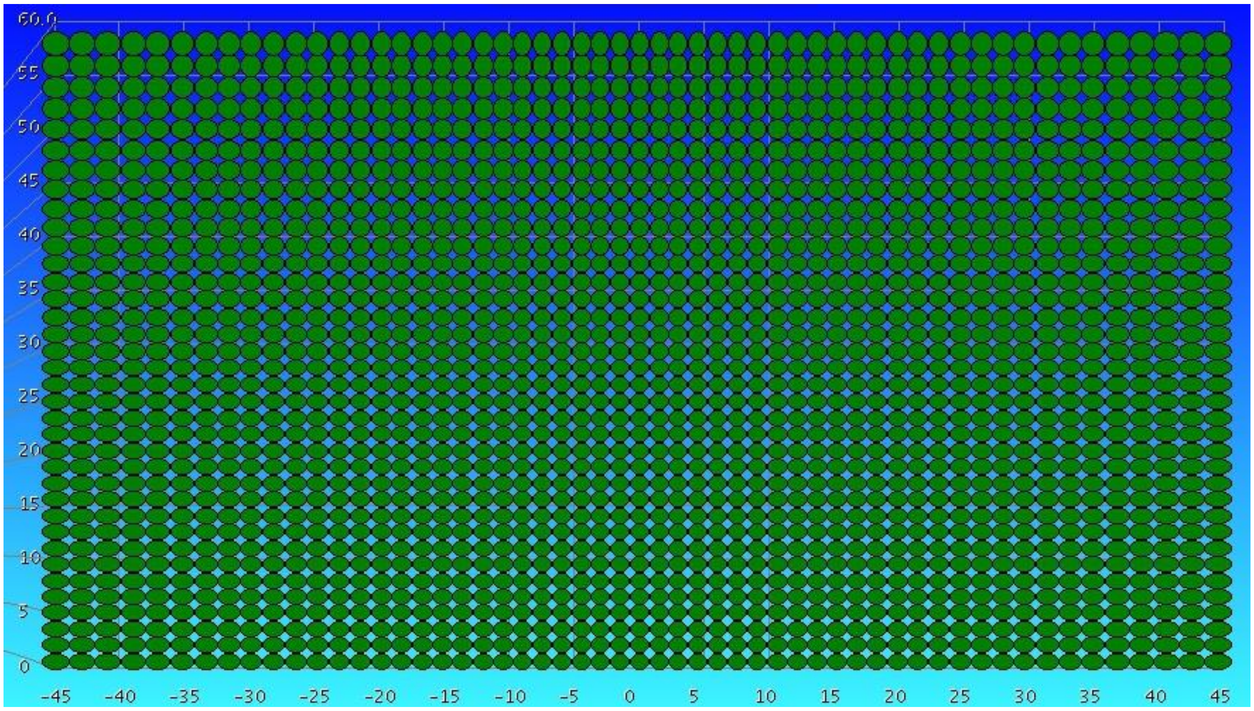

Fig. 3. RCI client ADAPTS beam map display for the full azimuthal extent of the fast surveillance, or detection, VCP. Green ovals represent all of the beam positions in the VCP. The shape and size of the ovals represent the beam coverage. Note non-overlapping beams and lack of gaps between elevations.

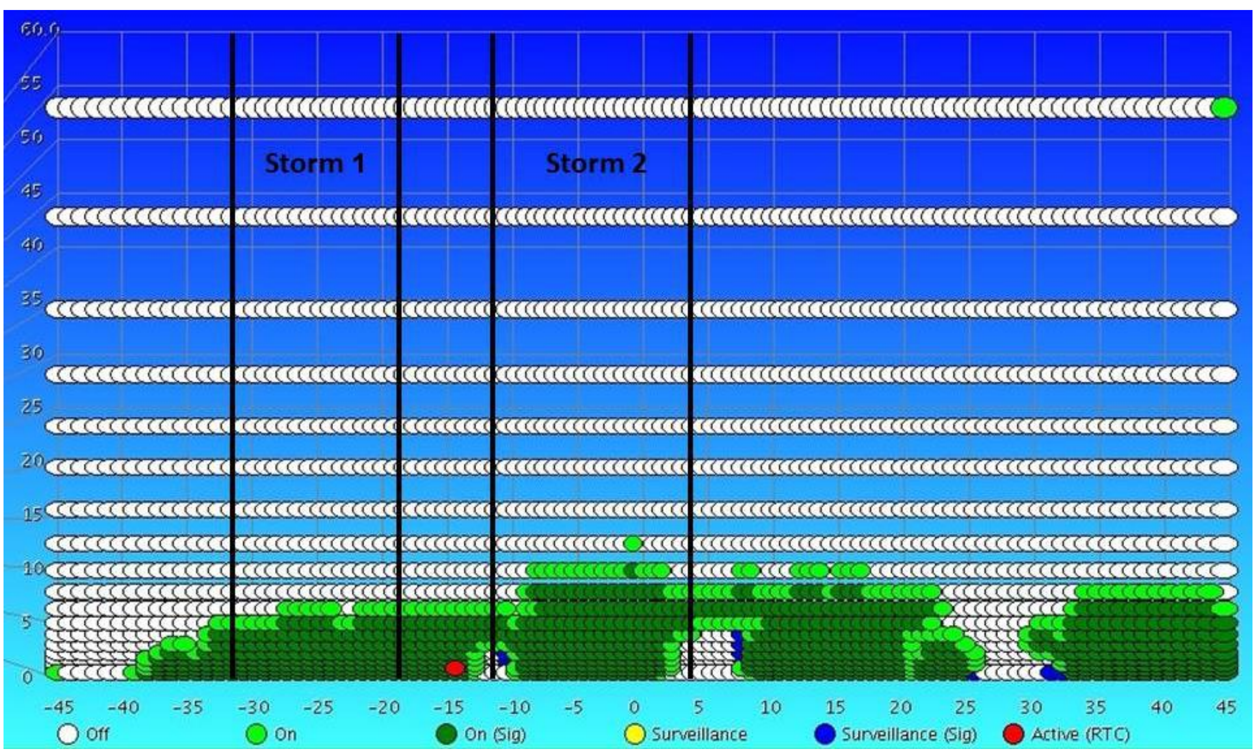

Fig. 4. RCI client ADAPTS beam map display for the full azimuthal extent of the general VCP at 13:31:31 UTC. White overlapping ovals represent inactive beam positions (not meeting reflectivity and continuity thresholds). Green overlapping ovals represent beam positions that are active by significance (dark green) or proximity to significant beams (light green). Blue overlapping ovals represent new active beam positions that meet the significance or proximity rules and were inactive in the previous volume scan. The red oval represents the current scan position in the active VCP.

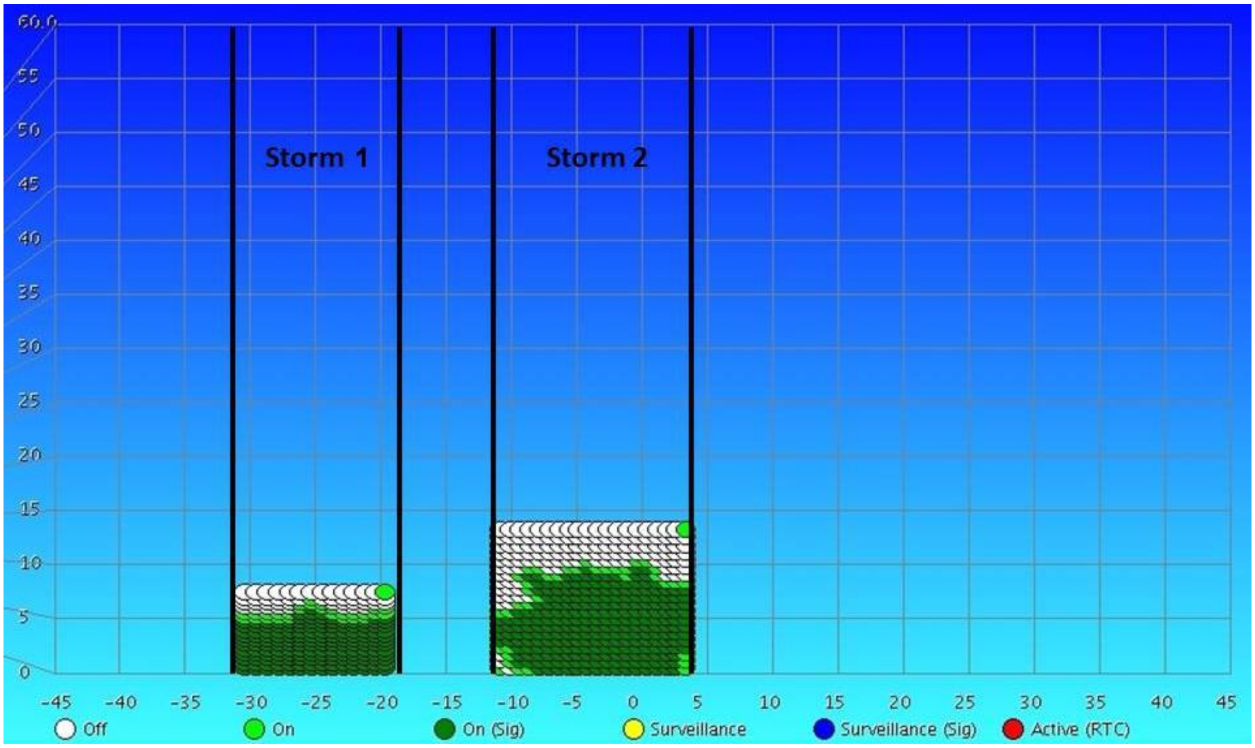

Fig. 5. Composite RCI client ADAPTS beam map display for both storm sector VCPs. The beam colors are the same as in Fig. 4.

Green and blue ovals represent significant and white ovals represent insignificant beam positions; significant beam are scanned and insignificant beams are not. The shape and size of the ovals represent the horizontal and vertical beam widths with respect to bore site. The antenna is tilted 10º above the horizontal so the beam with equal horizontal and vertical beam width is located at 0º azimuth and 10º elevation. Beams in the detection scan are always considered significant (active). Significant beam positions for the general and storm Sector VCPs are those which meet the reflectivity (11 dBZ <= 35 km; 9dBZ > 35 km) and continuity (4 gates) thresholds. The blue colored ovals represent significant beam positions which were identified as insignificant in the previous scan volume. During VCP processing at the RTC, all beam positions identified as insignificant are not scanned.

As previously mentioned, the detection scan uses a set of non-overlapping beams so ADAPTS can identify locations of precipitation within the antenna field of view that are VCP independent (Fig. 3). ADAPTS maintains a beam map for all active VCPs and integrates information from the detection scan into them, eliminating the need to run a periodic full scan to locate new echo development in the previously "un-scanned" regions. This is especially true for the general VCP.

The beam map for the general VCP is displayed in Fig. 4. If all of the beam positions were scanned, the VCP would require ~68 seconds to complete. By scanning only beam positions identified as significant, the VCP executed in ~38 seconds; a time savings of 30 seconds. Since the storms were distant from the radar, echoes were concentrated in elevations below 12º, accounting for much of the time savings. Some additional time was saved by not scanning echo free gaps in between storms.

A composite display of ADAPTS output showing active and inactive beam positions for the two storm sector VCPs is shown in Fig 5. Since storm sector VCP elevations are limited by maximum storm height at storm range, the uppermost elevation is much lower for both storm sector VCPs than for the general VCP. Storm 2 was furthest from the radar so the storm sector 2 VCP top scan elevation was lower than the storm sector 1 VCP top scan elevation. Also note the increased vertical sampling of the storm sector VCPs relative to the general VCP (Fig. 4). Unlike for the general VCP, ADAPTS provides minimal time savings for the storm sector VCPs. This is an expected behavior as storm sector VCPs are focused on regions known to contain precipitation and restricted in elevation to the maximum expected storm height.

4. SUMMARY

As phase array technology evolves, it will be important to exploit the electronic steering ability of the antenna when considering how to scan the atmosphere. New adaptive scanning techniques are being developed for the NWRT PAR with a goal of reducing scan update times and providing improved sampling in and around severe weather leading to earlier detection and improved warning. Work is continuing at the NWRT PAR to automate the storm selection and scheduling process.

5. ACKNOWLEDGEMENT

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