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

David Priegnitz[1,2], Pamela L. Heinselman[2], and Rodger A. Brown[2]

[1]*Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, Norman, OK, USA*

[2]*NOAA/National Severe Storms Laboratory, Norman, OK, USA*

(Dated 15 July 2014)

1. Introduction

The National Weather Radar Testbed (NWRT) Phased Array Radar (PAR), located in Norman, Oklahoma, has been a valuable resource for demonstrating new scanning techniques to reduce scan update times (Torres et al. 2012, Heinselman and Torres 2011, Yussouf and Stensrud, 2010). The positive benefits of faster scan updates in the detection and forecasting of severe weather have been well documented (Heinselman et al. 2008, 2012). Agile beam antennas have an advantage over mechanically steered antennas in that volume scanning can be focused on selected regions without worrying about the physical limitations of mechanical steering. Priegnitz and Heinselman (2013) described a technique to identify, track, and schedule storm sectors at the NWRT PAR, further reducing scan update times inside the storm sector. While the previous studies have focused on improving temporal sampling, little effort has been done to investigate the benefits of improving spatial (vertical) sampling.

Volume Coverage Patterns (VCPs) used by operational weather radars in the United States contain fixed sets of elevation angles for scanning the vertical structure of weather. Typically, these VCPs oversample in elevation at lower elevations and undersample in elevation at higher elevations, leaving gaps in the vertical coverage of storms near the radar. Both oversampling at lower elevations and undersampling at higher elevations are maximized when storms are located near the radar. Brown et al. 2000 described an optimized VCP method to generate a set of elevation angles that would maintain a specified maximum height underestimate at all ranges. This method led to the development of VCP 12, implemented on the WSR-88D radar (Brown et al. 2005). One drawback to VCP 12 is that with an upper-elevation limit of 19.5°, the upper portion of deep convection can become undersampled within 50 km of the radar. To improve scanning of deep convection at ranges within 50 km, an extension of VCP 12 (enhanced VCP 12) has been implemented at the NWRT PAR that includes five additional elevation angles, up to 52.9°.

One issue with the enhanced VCP 12 (or all one size fits all VCPs for that matter) when used for focused storm scanning, is that the benefits of additional low elevation scans is inversely proportional to storm range. When storms are close to the radar, it would be beneficial to add additional upper elevation scans in lieu of the extra low elevation scans. In addition, elevation scans below 8º are typically collected in batch or split cut mode to get the benefit of both higher Nyquist velocities and longer reflectivity ranges. When storms are close in range, batch or split cuts can be unnecessary. This paper describes a new automated VCP algorithm that creates VCPs with vertical coverage tailored to the storm range. Incorporated into the adaptive storm scheduling function at the NWRT PAR, this algorithm is applied to storm clusters chosen for focused scanning by the operator. PAR data collected with the storm VCP algorithm and the enhanced VCP 12 are compared.

2. VCP Algorithm

A goal of the storm VCP algorithm is to provide improved vertical sampling of a storm without sacrificing scan update times or data quality. To achieve this, a number of factors have been taken into consideration. These include: minimum and maximum vertical separation between elevations, storm range and height, and dwell time.

Starting with the lowest elevation angle (0.5° is the lowest elevation angle allowed at the NWRT PAR), scan elevation angles are determined through an iterative process. At storm range, the half beamwidth distance is calculated. For a planar phased array antenna, the beamwidth increases with increasing angle from boresite. The following formula can be used to calculate the angle adjusted beamwidth:

$$bw = 1.5/\cos(elevation - 10)$$

Where, *bw* is the angle adjusted beamwidth, *1.5* is the beamwidth of the NWRT PAR at boresite, *elevation* is the elevation angle above horizontal, and *10* is the fixed vertical slant angle of the antenna. If the half beamwidth distance is greater than 1 km, the next elevation angle is set to 1 km above the previous elevation angle at storm range. If the half beamwidth distance is less than 0.5 km, the next elevation angle is set to 0.5 km above the previous elevation angle. Since the number of VCP elevation angles is inversely proportional to storm range, an additional field, transition height, is added to control scan update times without adversely affecting vertical coverage. Elevation steps of 0.5 km below and 1 km above the transition height are used. It is assumed that reducing the vertical resolution above the transition height to 1 km is acceptable.

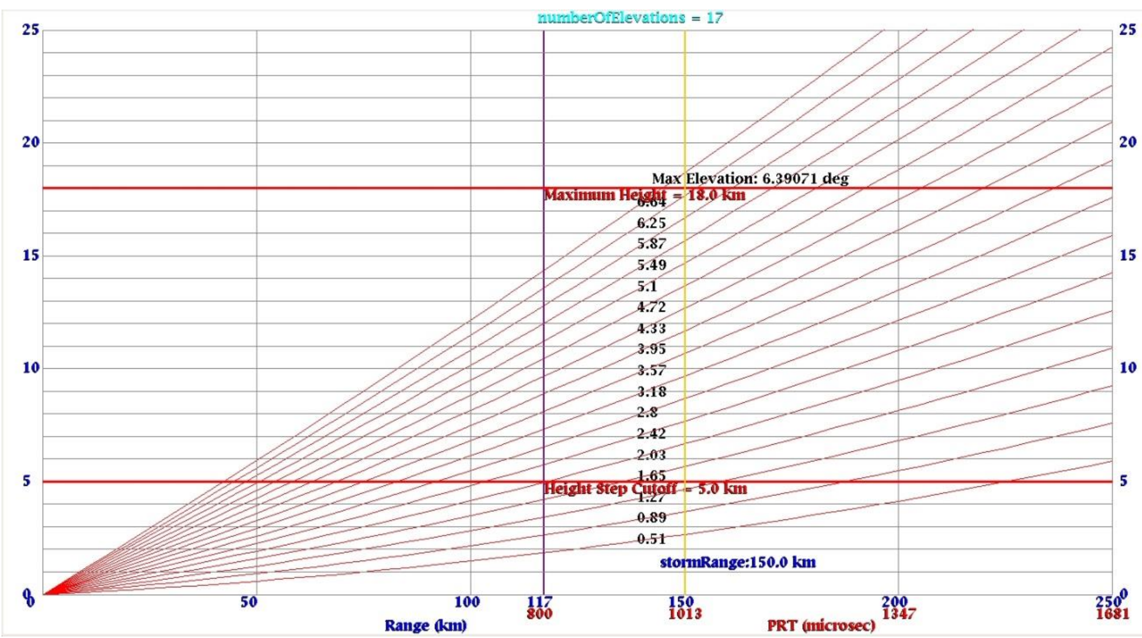

Fig 1. Profile of Storm VCP algorithm elevation angles for a storm at 150 km range.

A graph of storm VCP algorithm elevation angles for an 18 km tall storm, located 150 km from the radar, is shown in Fig 1. The half beamwidth separation at boresite at this range is 1.9 km (half beamwidth for NWRT PAR is ~0.75° at boresite) which is larger than the maximum threshold. So the vertical separation between elevation angles is set to 1 km. The storm VCP algorithm contains 17 elevation angles, starting at 0.5° and ending at 6.84°. Split cut multi-PRT mode is used for all elevation angles since the storm range is further than the unambiguous range of the Doppler PRT (800 microseconds). Using a dwell time of 40 milliseconds for split cut elevation angles (20 milliseconds for each long and short PRT), the total time to sample a vertical slice at a given azimuth angle is 0.68 seconds.

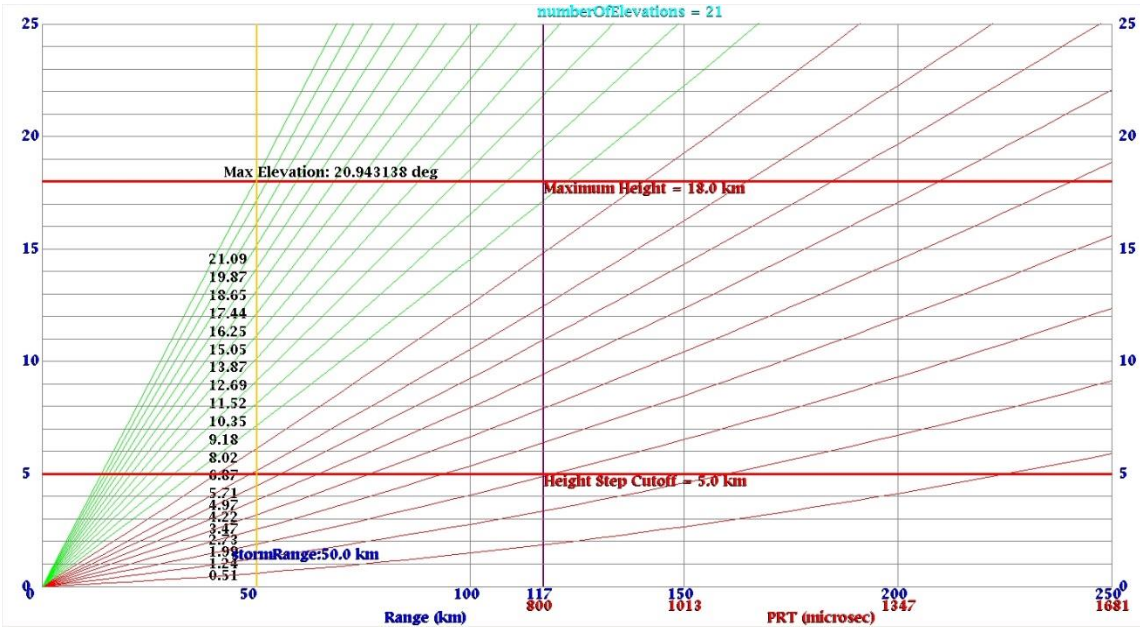

Fig 2. Profile of Storm VCP algorithm elevation angles for a storm at 50 km range.

A graph of storm VCP algorithm elevations for an 18 km tall storm, located 50 km from the radar, is shown in Fig 2. The half beamwidth separation at boresite for this range is 0.65 km. The vertical separation between elevation angles starts at 0.65 km at the lowest elevation. The storm VCP algorithm contains 21 elevations, starting at 0.5° and ending at 21.09°. Dwell times of 20 milliseconds are used for uniform elevation angles (green lines) and 40 milliseconds for split cut elevation angles (red lines). The total vertical slice scan time is 0.62 seconds.

Volume scan time can be determined by multiplying the number of azimuth positions in a sector by the vertical slice time. For a given storm size, the volume scan time is inversely proportional to the range from the radar since sector width decreases with range. For the NWRT PAR, volume scans are typically oversampled in azimuth by one half beamwidth resulting in a volume scan time of ~5.1 seconds for a 10 km wide storm at a range of 150 km and ~9.9 seconds at a range of 50 km (storm centered at boresite).

Shown below is a table listing by range, the number of storm VCP algorithm elevation angles, maximum storm VCP algorithm elevation angle, the storm VCP algorithm vertical slice scan time at a given azimuth angle, and the number of VCP 12 elevation angles required to scan storms with a maximum height of 18km.

Storm Range (km)	# Storm VCP Elevations	#VCP 12 Elevations	Top Storm Elevation (deg)	Slice Time (sec)
20	24	14	65.5	.60
40	23	14	26.8	.66
60	20	14	17.7	.60
80	18	13	12.8	.58
100	18	12	10.3	.64
120	18	11	8.7	.70
140	17	10	7.0	.68
160	17	9	6.2	.68
180	16	9	5.3	.64
200	15	8	4.5	.60

Although the storm VCP algorithm vertical slice time for storms at a range of 20 km and 200 km are the same (0.6 seconds), there are 9 more elevations at a range of 20 km. This is achieved by eliminating 4 low elevation split cuts and replacing them with 9 mid-upper level uniform PRT cuts. At a range of 200 km, the storm VCP algorithm provides 15 vertical samples whereas VCP 12 provides only 8.

3. April 13, 2014 Case Study

On April 13, 2014 an evolving line of severe thunderstorms developed to the north of the NWRT PAR, with storm initiation occurring on the southern flank. A new storm, approximately 50 km in range, was selected by the operator for tracking and focused scanning. Radar scheduling was set up so that multiple storm VCP algorithm VCPs would be interrupted every ~60 seconds by an enhanced VCP 12 scan. The storm VCP algorithm scanning was focused on a smaller sector encompassing the storm. This provided an opportunity to compare storm structure between the focused storm VCP algorithm VCP and the enhanced VCP 12.

Fig 3 contains sets of three different reflectivity views of the storm at two different times; an RHI cross section, a 0.5° PPI, and an 8 km CAPPI. Interpolation was disabled in the RHI cross section and CAPPI products to emphasize the sampling differences between the two VCPs. The tracked storm is highlighted by the white circles in the PPI and CAPPI views. Data shown in Fig 3 (A) are from the storm VCP scan at 193525 CDT and those from Fig 3 (B) are from the enhanced VCP 12 scan 9 seconds later at 193534 CDT.

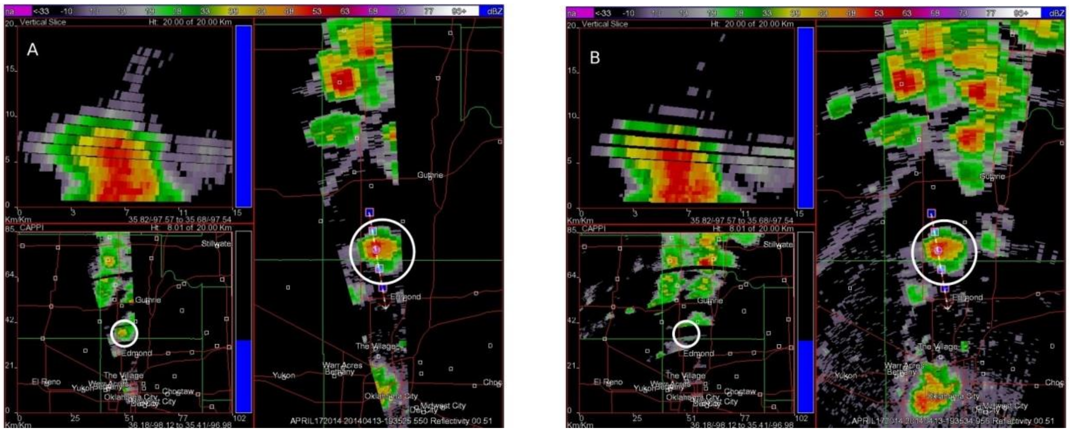

Fig 3. Multiple views of a storm selected for focused scanning. Top left image is an RHI cross section; lower right image an 8km CAPPI; right image a 0.5º PPI. Frame A was from 193525 CDT using the storm VCP algorithm VCP. Frame B was from 193534 CDT using the enhanced VCP 12.

As expected, the most noticeable differences between the storm VCP algorithm VCP and the enhanced VCP 12 scans are in the RHI cross section and CAPPI products. While the enhanced VCP 12 scan contains more beams below 2 km in height than the storm VCP algorithm VCP, it leaves gaps in the storm coverage above 5km; whereas the storm VCP algorithm VCP does not. These gaps are especially evident when comparing the 8 km CAPPI images; most of the storm core is mostly absent at that height in the enhanced VCP 12 scan. Although the storm VCP algorithm VCP provides fewer samples at heights below 2km, little value is added by the additional enhanced VCP 12 elevation angles.

4. Summary

To further enhance the adaptive scanning capabilities of the NWRT PAR, a range-based VCP algorithm has been developed to improve vertical spatial resolution without sacrificing scan update time. Preliminary analysis has shown improved vertical sampling when storms are close (within 50 km) to the radar. Only a single case study was presented in this paper and further study needs to be done to determine the benefit of improved vertical sampling, if any, for storms at farther ranges. With new initiatives like Warn on Forecast, it is important to consider the spatial resolution of the radar data going into the numerical models.

Acknowledgement

Support for this paper and research was provided by NOAA/Office of Atmospheric Research under NOAA-University of Oklahoma Cooperative Agreement #NA11OAR4320072, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of NOAA and the U.S. Department of Commerce.

References

Brown, R. A, V. T. Wood, and D. Sirmans, 2000: Improved WSR-88D scanning strategies for convective storms. *Wea. Forecasting*, **15**, 208-220.

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.

Heinselman, P. L., and S. M. Torres, 2011: High-temporal resolution capabilities of the National Weather Radar Testbed Phased-Array Radar. *J. Appl. Meteor. Climatol*., **50**, 579-593.

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., D. S. LaDue, and H. Lazrus, 2012: Exploring impacts of rapid-scan radar data on NWS Warning Decisions. *Wea. Forecasting*, **27**, 1031-1044.

Priegnitz, D. L., and P. Heinselman, 2013: Detection and adaptive scheduling on the NWRT Phased-Array Radar. Preprints, *36th Conf. on Radar Meteorology*, Breckenridge, CO, Amer. Meteor. Soc.,Paper 147.

Torres, S., R. Adams, C. Curtis, E. Forren, I. Ivic, D. Priegnitz, J. Thompson, and D. Warde, 2012: New weather-surveillance capabilities for NSSL's Phased-Array Radar. Preprints, *29th Conf. on Environmental Information Processing Technologies*, Austin, TX, Amer. Meteor. Soc., Paper 8.2.

Yussouf, N., and D. J. Stensrud, 2010: Impact of phased-array radar observations over a short assimilation period: Observing system simulation experiments using and ensemble Kalman filter. *Mon. Wea. Rev*., **138**, 517-538.