7.4: A Polar-Coordinate Real-Time Three-Dimensional Rapidly Updating Merger Technique for Phased Array Radar Scanning Strategies

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Abstract

The National Weather Radar Testbed (NWRT) phased array radar will not be operated in fixed volume coverage patterns. Instead, the phased array radar will attempt to simultaneously maximize the utility of several possible uses, such as 3D storm analysis, area surveillance and aircraft tracking. In order to do so, the phased array radar will employ adaptive scanning and intersperse meteorological scans with aircraft tracking. To a downstream visualization program or automated severe-weather detection algorithm operating on phased array radar data, the incoming stream will be randomly organized in space and time. It is up to the application to create a coherent view of the atmosphere from the phased array radar beams.

In this paper, we describe a method of creating such a coherent view. In polar coordinates, this involves creating a rapidly updated ”virtual volume scan”. The virtual volume scan is created by treating each of the phased array radar range gates as ”intelligent agents” that place themselves in the resulting polar grid, know how to collaborate with other agents to create optimal estimates of the radar values at each range gate of the virtual volume and know when they have either been superseded or are too old. The resulting virtual volume, created in real-time, is used by the downstream applications. This enables the downstream applications to work with a regularly spaced grid that is created at periodic intervals.

1. Motivation

The U.S. Navy loaned a SPY-1 phased array radar to the National Severe Storms Laboratory (NSSL) in 2000 and provided the initial funding to help build the National Weather Radar Testbed (NWRT). NSSL adapted the Navy radar for severe weather tracking so that the NWRT became operational in 2003 and data have been collected with the radar since May 2004 (Forsyth et al. 2005).

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Conventional Doppler radar such as those used operationally in the United States by the National Weather Service and the Federal Aviation Authority rely on mechanical scanning. It is necessary to mechanically move the radar to point towards the area being scanned. Mechanically scanned radars are used operationally in terms of volume coverage patterns, defined in terms of the elevation angle, azimuths scanned and the pulse repetition frequency used. The WSR-88D VCP 21(Crum and Alberty 1993; Smith 1995) (shown in Figure 1) is repeated every six minutes. The volume coverage pattern thus defines the spatial and temporal resolution with which a 3D conical volume around the radar is scanned.

The phased array radar, on the other hand, does not rely on mechanical scanning. Radar beams are directed independently at different locations in the 3D volume being scanned, so that different parts of the area can be scanned at different spatial and temporal resolutions. This enables the phased array radar to scan storms at higher resolutions than clear air, repeatedly sample areas of interest at different pulse repetition frequencies. The electronic scanning is also much faster and the beams multiplexed, so that an entire volume can be scanned in 50 seconds as compared to the 360 seconds it would take for VCP 21 McNellis et al. (2005). It is also possible for the radar to scan different areas at different resolutions, depending on the active weather at that location, so as to further increase the temporal sampling of thunderstorms. The phased array radar can also perform several tasks at once. In particular, it can both track aircraft and scan the atmosphere for weather.

Thus, phased Array radar are a promising technology because they possess the ability to send radar beams in several directions at once, potentially sensing a 3D volume of the atmosphere in just a few seconds (compared with 5-6 minutes and significant vertical blind-spots for a conventional weather radar). This advantage of phased array radar to simultaneously sense different areas of the atmosphere is, however, a significant challenge to downstream applications. Downstream applications are used to dealing with radar beams arriving one after the other, with each beam scanning a slice of the atmosphere adjacent to the previous beam. In a phased array radar, the synchronized radar beams have been replaced by an asynchronous stream of randomly situated radar beams. This makes designing analysis and visualization applications especially hard.

It is up to the application to create a coherent view of the atmosphere from the phased array radar beams. In Section 2, we describe a method of creating such a coherent view. Because the NWRT PAR is not yet configured to perform adaptive scanning, a randomized input stream was created. The simulation to create the randomized input stream is described in Section 3. Examples of products created from the virtual volume using the method of this paper are shown in Section 4.

2. Method

It is up to downstream applications that use phased array radar data to create a coherent view of the atmosphere from the adaptive and repetitive scans of the radar. Such a coherent view can be formed by creating a “virtual volume” of the atmosphere. The range gates of this virtual volume are assigned values by combining values from all the rays that affect that location.

Each of the range gates in the phased array radar beams will be an intelligent agent imbued with the ability to know where it impacts the final result, in what direction it should move with time, when it ceases to be useful, and when it should update itself with new values. The challenge here is to imbue the intelligent agent with all of this information appropriately. In traditional radar data, where we used the intelligent agent methodology to create multi-radar 4D grids and products (Lakshmanan et al. 2006), the task of programming the intelligent agents was made much simpler by the fact that the radars behave in anticipatable ways (the VCPs again). Thus, each agent knows the agents that it will interact with, because the agents that will be created by the next scan of the radar can be anticipated. Because a phased array radar is much less anticipatable, the intelligent agents have to have much more context. The agents in this case monitor their immediate neighborhood and collaborate with whichever agents they find in that neighborhood.

The intelligent agents collaborate to build a constantly updating 3D earth-relative grid in polar coordinates. The output grid is of constant resolution in cylindrical coordinates (we chose a 0.5 degree resolution in azimuth and elevation and 0.5km resolution in range for this study), and the value of each point in this 3D grid will be set through active collaboration by the various agents. This 3D grid is written out in a self-describing NetCDF format such that it can be incorporated into existing radar analysis algorithms such as those in the Warning Decision Support System(WDSS; Lakshmanan et al. (2007)).

The collaborative value produced by the intelligent agents can follow one of several strategies – we could use simply the latest value, the nearest neighbor or a weighted average of the values. One appropriate choice is to choose as weights, the power-density (Doviak and Zrnic 1993) of the beam at the grid-point such that the highest power is at the center of the beam. In the results demonstrated here, a power-density weighting is used.

3. Simulated Input

The research being presented is being performed in anticipation of requiring visualization and data analysis algorithms when the NWRT phased array radar is used in an adaptive scanning mode. At present, the radar is used only to create traditional sector scans. Therefore, the input to the polar merger algorithm was simulated from real data.

Data collected by the WSR-88D radar at Twin Lakes, Oklahoma City (KTLX) on May 3, 1999 was used for this purpose. Complete volumes of this data were taken and split arbitrarily into sectors. The sectors were then randomly rearranged (so that sectors at different elevation angles could follow each other). The time on the sectors was modified so that it appeared that sectors at different elevation angles followed each other.

The first few frames of the input sequence are shown in Figure 2.

4. Results

The output grid was created at $0.5^o \times 0.5km$ resolution at elevations starting at 0 degrees and going up to 10 degrees in increments of 0.5 degrees. The complete 3D grid was created every 60 seconds. A given grid point will be affected by multiple beams. The final value at a grid point is a weighted sum of these observations, with the weight of any observation depending on the distance of the grid point from the center of the beam that the observation comes from. The weighting function used was the power density function given by Doviak and Zrnic (1993).

The first three frames of the 1-degree elevation scan (produced every 60 seconds) is shown in the top row of Figure 3. A composite image created from all the elevations is shown in the middle row. The 1-degree elevation scan was chosen because it is truly virtual – the WSR-88D VCP used at the KTLX radar on May 3, 1999 provided 0.5 and 1.5 degree elevation scans, but none at 1 degree. The 0.5 and 1.45 degree scans (before randomization) from approximately the same time is shown in the bottom row. Note that the input scans are at $1^o \times 1km$ resolution.

Cross-sections through the virtual volume are shown in Figure 4.

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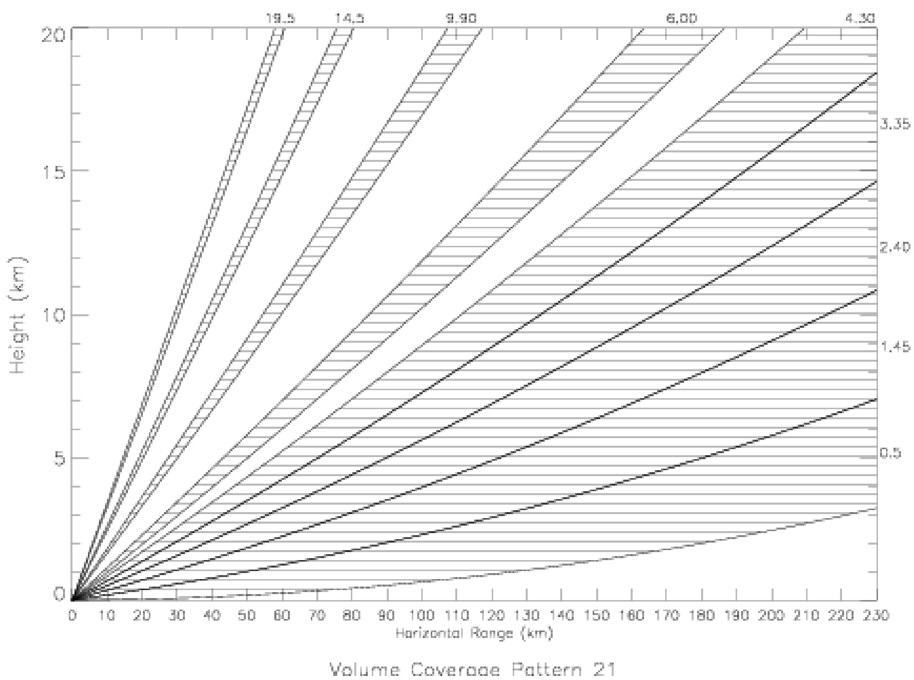


Figure 1: Volume coverage pattern (VCP) 21 of the WSR-88D. The VCP defines a regular scanning strategy and is commonly applied to mechanically scanning radars in operational settings.

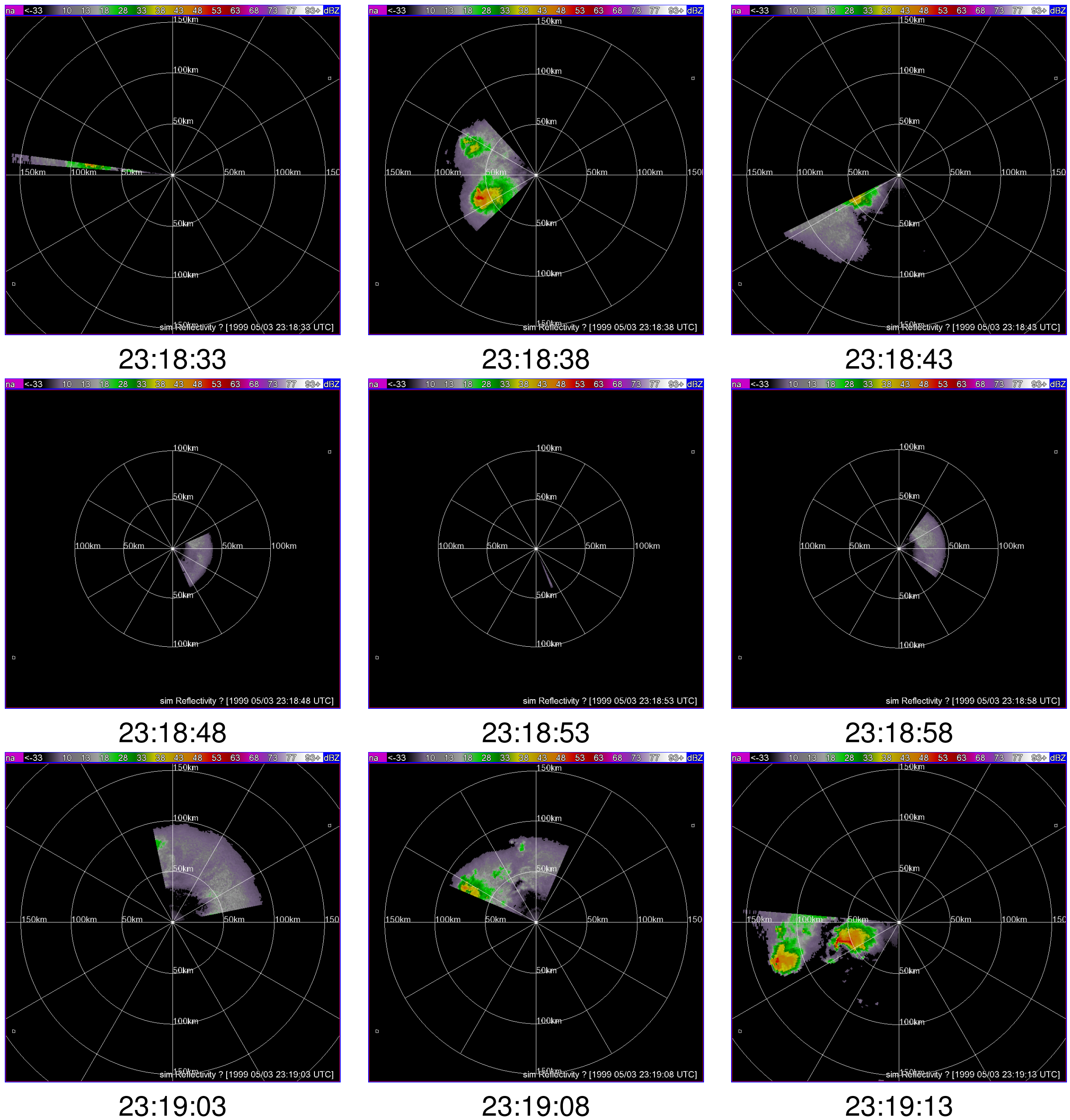
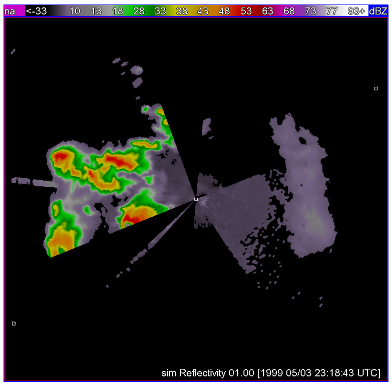


Figure 2: First few sectors of the simulated input sequence provided to the algorithm. The data are from KTLX on May 3, 1999, but have been randomly split into sector scans. The times of the sector scans are simulated. Since the range rings go out to lower distances at higher elevation scans, the extent of the range rings gives an idea of the elevation angle of the sector scan depicted.



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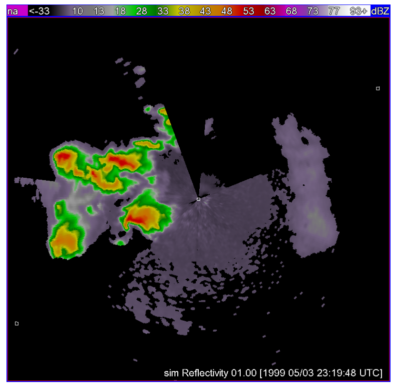
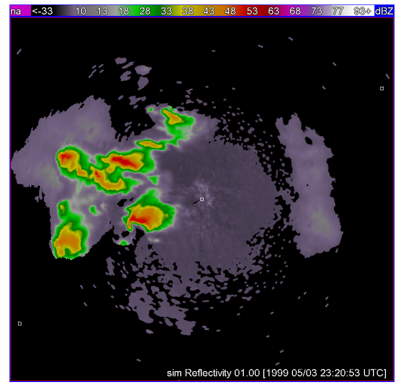
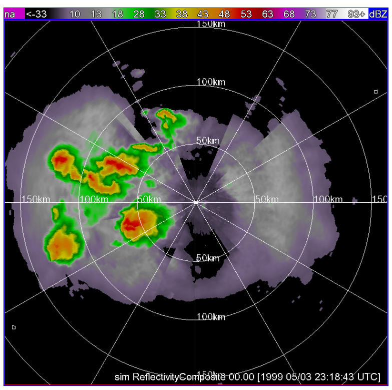


23:19:48



23:20:53



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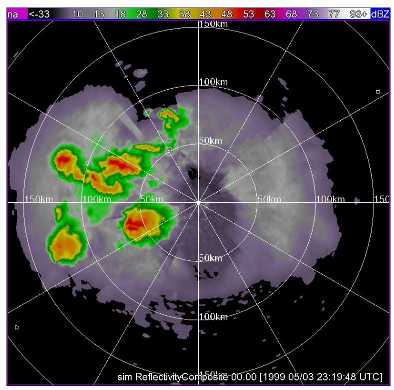

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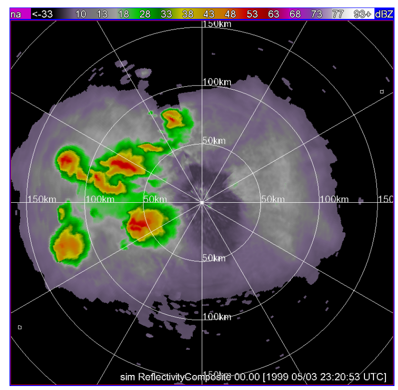

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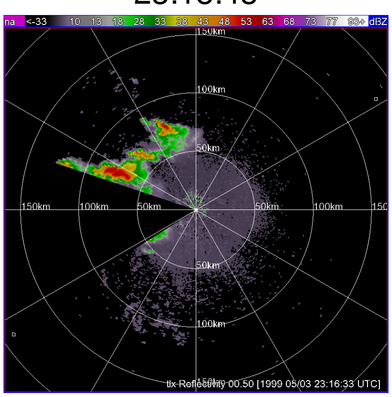
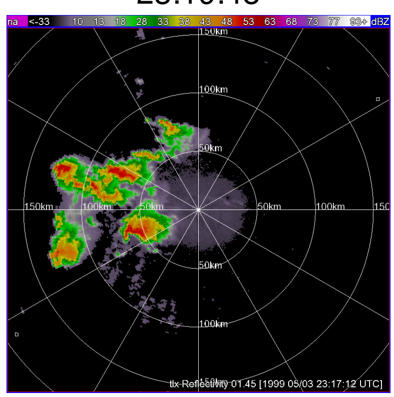
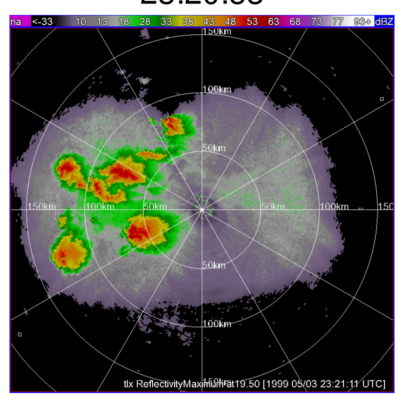


0.5-deg scan at 23:16:33



1-deg scan at 23:17:12



Composite at 23:21:11

Figure 3: Top row: first few frames of reflectivity from the virtual volume at 1 degree. Middle row: first few frames of composite reflectivity from the volume volume from 0 to 10 degrees at 0.5-deg, 0.5-km resolution. Bottom row: The 0.5-degree, 1.45 degree and composite reflectivity images from KTLX before randomization.

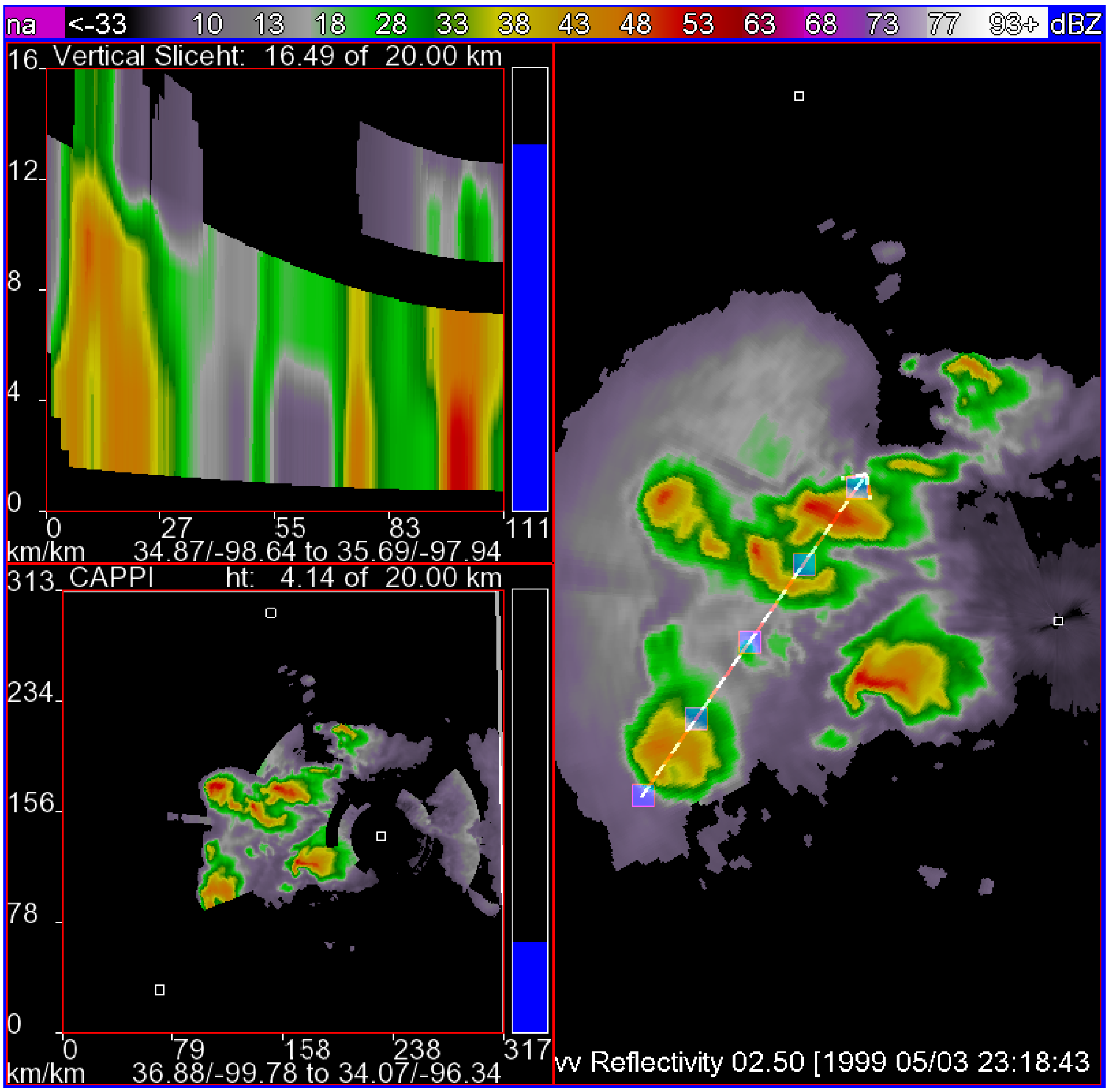


Figure 4: Cross-section and CAPPI through virtual volume.