19 Enhancements to the National Weather Radar Testbed Phased Array Radar Storm Tracking Function

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1. INTRODUCTION

The National Weather Radar Testbed (NWRT) Phased Array Radar (PAR), located in Norman, Oklahoma, consists of a single antenna array capable of electronically scanning a 90-degree azimuthal sector at any given moment (Zrnić et al. 2007). The antenna, mounted on a pedestal that can be commanded to move to any azimuthal position, allows operators to select the center of the best electronically scanned 90-degree sector to follow areas of interesting weather. At the previous IIPS conference, an adaptive pedestal-control algorithm that automates the process of tracking an operator-defined weather feature was presented (Priegnitz et al. 2012). The algorithm provides feedback to the radar control software to adjust the antenna pedestal position in order to continuously keep the weather feature in the field of view.

The tracking algorithm is part of a collection of new algorithms being used to demonstrate the adaptive capabilities of phased array radar in the detection and monitoring severe weather. These new algorithms make tracking more robust, improve data quality (Torres et al. 2011) and aid in the detection of weather features. Improvements to the ADAPTS algorithm (Torres et al. 2013) have helped reduce overall scan times, leading to faster detections. Heinselman et al. (2008) demonstrated the benefits of faster scan updates in the detection and monitoring of severe weather. Scan update times could be further reduced by scheduling smaller sectors that contain the most intense weather. The tracking algorithm was designed to support the tracking of a selected weather feature, providing sector information which can be used by future scan scheduling software (e.g., Yu et al. 2011). These algorithms will provide the framework for demonstrating adaptive scanning techniques at the NWRT PAR.

2. TRACKING ALGORITHM

The original tracking algorithm uses the reflectivity data from the lowest elevation to locate and track weather features. A tracking box (i.e., a rectangle in polar coordinates) encompassing the weather feature, defined by a human operator at the Radar Control Interface (RCI), is sent to the tracking algorithm during activation. The tracking algorithm waits for the first (lowest) elevation cut to be completed and then calculates the weighted centroid of the gates inside of the tracking box; the weight is determined by subtracting a user specified threshold, squaring the result, and adding 1. The position of the weighted centroid with respect to the center of the tracking box is then determined. In subsequent scans, a new weighted centroid is calculated, and the tracking box is adjusted in order to keep the new weighted centroid in the same relative position within the box (the size of the box remains constant). This process is repeated until the tracking box becomes close to the edge of the scan sector, at which time the tracking algorithm commands the antenna to a new optimal position.

Using the reflectivity data from the lowest elevation for tracking storms may not work well in all situations. For example, near the radar, ground clutter residue may contaminate the reflectivity field inside the tracking box, making it difficult to get an accurate centroid position. Also, the tracking algorithm may not perform well when tracking storms embedded in widespread precipitation. To mitigate these and other types of issues dealing with reflectivity data at the lowest elevation, a 3D option was added to the tracking algorithm.

The 3D option utilizes the reflectivity data from all elevations in a volume scan. The same weighted centroid process is performed at all elevations in the scan volume. The weighted volumetric centroid is calculated from the

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weighted centroids at all elevations. Since the user-defined tracking box is based on the lowest elevation, to preserve the vertical structure of the weather feature, the size of the tracking box at each higher elevation is adjusted in range. Since the result is more gates inside the tracking box with increasing elevation, the weighting factor for each gate is decreased accordingly at the higher elevations. Once the centroids at each elevation are calculated, the volumetric centroid is determined.

3. AUTO-PRT ALGORITHM

When tracking severe weather, the pulse repetition time (PRT) used to determine radial velocities in batch and split cuts may not be suitable for the weather feature being tracked. Returns from distant echoes may obscure important radial velocity structures. Changing the PRT could help minimize the obscuration at and around the weather feature. However, determining the optimal PRT can be difficult to do manually if there is widespread precipitation in the sector containing the weather feature.

A manual PRT adjustment feature has been part of the NWRT PAR RCI for several years, and has proven useful during numerous data collection efforts. However, this feature has been limited in scope and doesn't provide an operator with an optimal PRT to use. In addition, the operator must wait for the completion of a new scan to determine if the PRT adjustment was adequate.

With this in mind, an auto PRT algorithm was developed that, when used in conjunction with the tracking algorithm, determines an optimal PRT to use in split/batch cuts. This minimizes the obscuration of radial velocities inside the tracking box due to multiple-trip echoes. This information is then passed back to the radar scheduling software and applied to the split/batch dwells in subsequent scans. The operator can define a maximum PRT to consider in order to set a lower Nyquist velocity limit. This is especially important in situations where high radial velocities are present.

4. CLUSTER IDENTIFICATION

The process of identifying weather features can be difficult at times; especially in situations of widespread embedded convection. Whereas drawing a box around a weather feature so it can be tracked is fairly straightforward, in time, the weather feature will most likely change in both intensity and in size. In situations with fast moving storms, a small tracking box is sensitive to the scan update time while a large tracking box is sensitive to new development and may prevent the tracking algorithm from keeping the weather feature inside the tracking box. To adjust to the changing structure of the weather feature, an operator may be required to redefine the tracking box multiple times and restart tracking, taking valuable time away from other, more important duties.

To aid in the selection of a weather feature and to account for changes in size and intensity, a cluster identification algorithm has been implemented. This algorithm uses a technique described by Lakshaman et al. (2009) to organize a two dimensional set of data into discrete objects; in this instance, to organize the low elevation cut reflectivity field into a set of clusters. A cluster is defined as a region containing one or more watersheds (cells). A watershed is a region containing a single peak (reflectivity maximum) and valley (reflectivity minimum). This process is analogous to defining watersheds for hydrologic purposes using topographic data. In this case reflectivity is used instead of elevation.

Unfiltered, the reflectivity field is relatively noisy, and as a result, likely contains many watersheds. To reduce the “noise” a median filter is applied to the reflectivity field. The median filter replaces the value at a gate with the median value from gates within an influence zone surrounding the gate. The operator can control the influence zone around each gate by defining a radius of influence (in measured distance). A given influence zone will contain the most gates nearest and the least gates furthest away from the radar (since the data remain in a polar grid, the distance between beams increases with range). A larger radius of influence will produce a smoother data set, reducing the number of watersheds.

In addition to the median filter, the operator flattens the data by specifying minimum and maximum reflectivity thresholds. Gates with a reflectivity value below the minimum threshold are thrown out and those with a reflectivity value above the maximum threshold are set to the maximum. Eliminating gates below the minimum threshold further reduces the number of watersheds. The data are smoothed further by converting the floating point values into integers.

After the data are filtered and smoothed, the process of defining watersheds begins. Starting at the gate containing the highest reflectivity value, surrounding gates are added to the watershed if they contain smaller reflectivity values. This process is repeated for all gates assigned to the watershed and stops when no new gates are added. New watersheds are defined by repeating the same procedure for unassigned gates (starting at the gate with the highest reflectivity value) and terminates when all gates are assigned to a watershed.

The final step is to reduce the number of watersheds by combining them into clusters. The operator can define a minimum cluster size along with a radius of influence. The radius of influence determines which adjoining watersheds (foothills) are associated with a primary watershed (peak). The radius of influence is the distance from centroid of the peak watershed. Cluster processing begins with the highest ranked watershed (the one with the highest reflectivity value) and continues until there are no more unassigned watersheds.

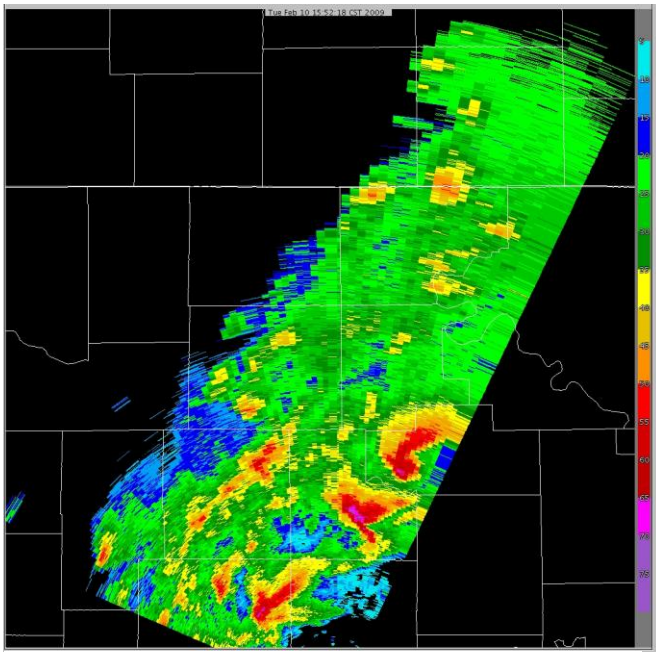
Fig. 1. Reflectivity display for 0.5-deg elevation cut at 15:52:18 CDT on 10 Feb 2009.

A PPI display of the 0.5-degree elevation reflectivity field from 15:52:18 CDT on 10 Feb 2009 is shown in 1. At this time there were several tornadic storms to the north of Oklahoma City. These storms were located in the southern part of a widespread region of precipitation extending into northern Oklahoma. A cluster analysis was performed on this data set using different values for the filters. Several watershed and cluster displays are presented to illustrate the effect of using different minimum reflectivity thresholds (Figs. 2 – 5). In all of the examples a median filter radius of 4 km was used.

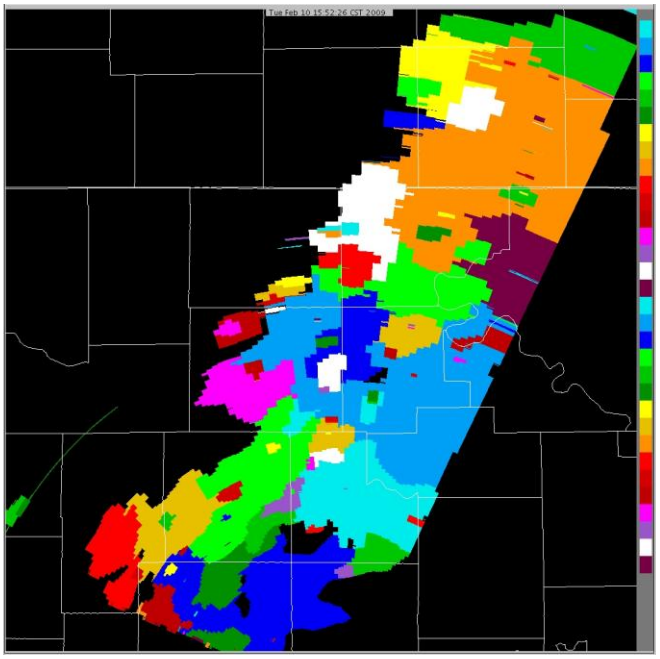
Fig. 2. Watershed display for the 0.5-deg elevation cut at 15:52:18 CDT on 10 Feb 2009 using a 20 dBZ minimum threshold.

A PPI display of the watersheds defined by the cluster algorithm using a reflectivity threshold of 20 dBZ is shown in Fig. 2. The colors differentiate watersheds which are given a numeric identifier by the algorithm beginning with 1 (highest priority) up to 32768 (lowest priority). The color scale in the display consists of 16 different colors. Since there are more watersheds than colors, the same color sequence is repeated in order to view all watersheds (i.e., watershed 1 will have the same color as watersheds 17, 33… W+16). The main purpose of this display is to show which gates are assigned to a watershed and provide some feedback about the performance of the watershed algorithm.

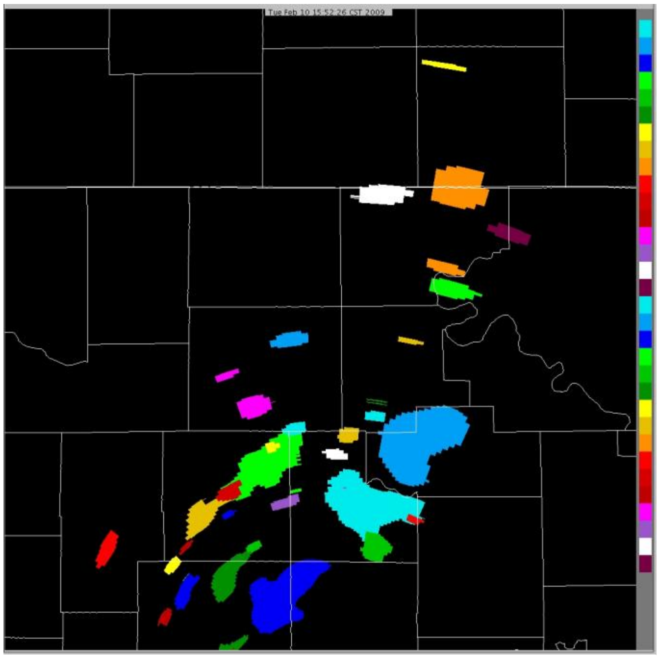

Fig. 3. Watershed display for the 0.5-deg elevation cut at 15:58:12 on 10 Feb 2009 using a minimum threshold of 35 dBZ.

A PPI display of the watersheds using a reflectivity threshold of 35 dBZ is shown in Fig. 3. Note the elimination of the weaker watersheds and better definition of the more significant storms.

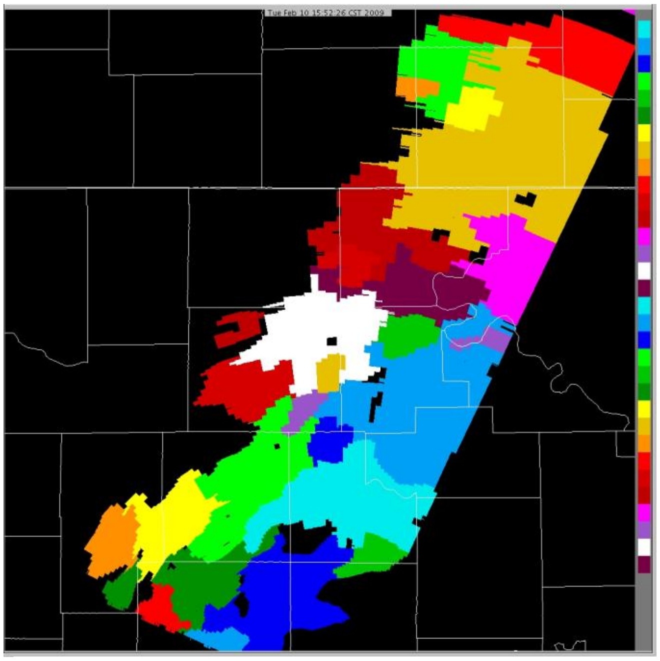

Fig. 4. Cluster display for the 0.5-deg cut at 15:58:12 CDT on 10 Feb 2009 using a minimum threshold of 20 dBZ.

A PPI display of the clusters using a reflectivity threshold of 20 dBZ and a radius of influence of 17.3 km (corresponding to an area of 300 km^2) is shown in Fig. 4. Clusters with areas less than 100 km^2 were rejected. Clusters were assigned a numeric value similar to the watershed analysis with the highest ranked cluster assigned a value of 1. The color scheme is identical to the one used to display watersheds.

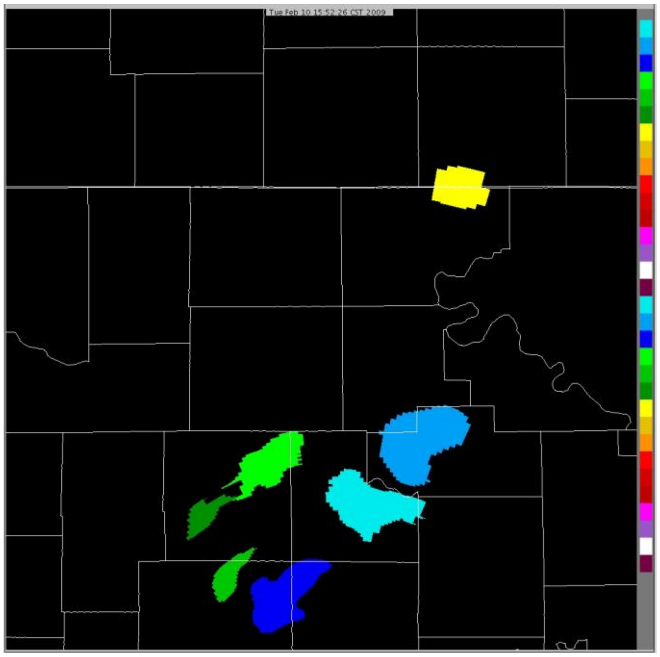

Fig. 5. Cluster display for the 0.5-deg elevation cut at 15:58:12 CDT on 10 Feb 2009 using a minimum threshold of 35 dBZ.

A PPI display of the clusters using a reflectivity threshold of 35 dBZ is shown in Fig. 5. Note the more manageable number of clusters. These clusters represent the strongest storms and the ones most likely to be tracked. One would expect a forecaster to want to monitor and track the most intense storms.

A PPI display of the reflectivity field with the 35 dBZ cluster sectors overlaid is shown in Fig. 6. This sector information can be useful to the tracking algorithm for identifying weather features and can eliminate the need for the human operator to draw a tracking box. All the operator would need to do is select which feature(s) to track.

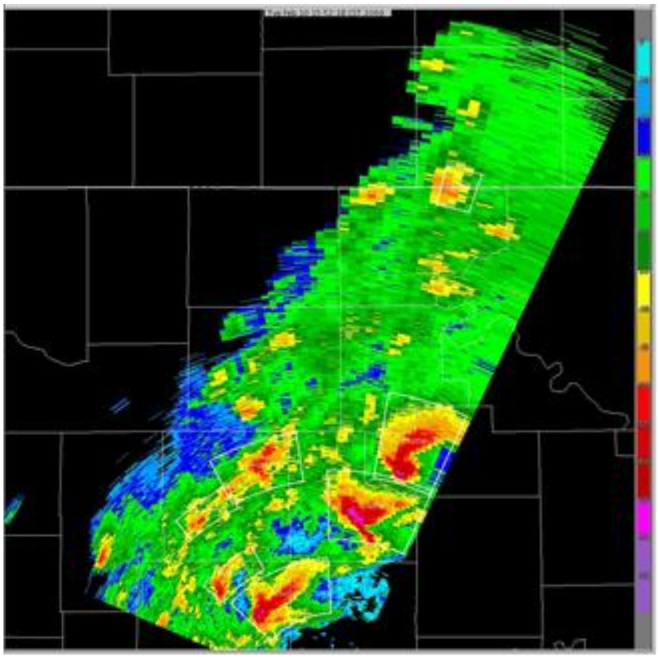

Fig. 6. Reflectivity display at the 0.5-deg elevation cut at 15:58:12 CDT on 10 Feb 2009 with cluster sectors overlaid (35 dBZ minimum threshold).

6. FUTURE WORK

Now that algorithms have been developed to identify and track weather features, the next step is to automatically schedule and adaptively track them. Work is currently underway to adaptively track and schedule weather features at the NWRT PAR this upcoming spring. Used in conjunction with ADAPTS, the new tracking and scheduling features will demonstrate the unique capabilities of phased-array radars to efficiently monitor and sample severe weather. A goal is to improve detection and monitoring of severe weather leading to improved warning lead times.

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