12.10 RADAR MOSAIC GENERATION ALGORITHMS BEING DEVELOPED FOR FAA WARP SYSTEM

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1.0 INTRODUCTION

The FAA WARP (Weather and Radar Processor) system acquires Level 3 radar product data from the CONUS WSR-88D radars and disseminates the data to other FAA systems. The WARP systems are installed at each of the FAA's CONUS in-route air traffic control centers, and generate a set of real-time regional radar mosaic products to support a user group that includes CWSU meteorologists, traffic managers, traffic planners, and air traffic controllers. The users range from skilled radar meteorologists to air traffic control personnel with limited meteorological training.

At the present time WARP mosaic products are generated using a highest-contributor algorithm. When significant contamination of WSR-88D product data by non-meteorological returns (RF interference, ground clutter, AP returns, etc.) exists, a highest-contributor algorithm produces dirty mosaic products which can be difficult to interpret, especially in the real-time air traffic control application.

Unisys is currently under sub-contract to the Harris Corporation, the prime contractor on the WARP program, to develop and implement an improved set of mosaic generation algorithms for the WARP system to remove the non-meteorological content from the WARP mosaic products. Our approach in developing these algorithms has been based on two (sometimes conflicting) goals:

1. Suppress non-meteorological returns.
2. Avoid removing valid weather returns.

While it is desirable to remove non-meteorological content, there is potentially a very severe penalty (lives lost) for removing valid weather returns. In developing these algorithms, when these two goals have conflicted, we have opted in favor of the second goal. The result is a set of real-time algorithms that significantly reduce the non-meteorological content of the mosaic products without significantly affecting weather returns.

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This paper contains an overview of a prototype algorithm developed for generating mosaic products from WSR-88D composite reflectivity product data. The process used to evaluate the performance of the prototype algorithms is also described. Examples are presented to illustrate the algorithm performance.

2.0 WARP MOSAIC GENERATION STRATEGY

The WARP regional mosaic products are generated from radar product data from up to 35 WSR-88D radars. Because of the time-critical nature of air traffic control operations, the mosaic products are dynamically updated as radar product data is received. When a new radar product is received, all mosaic product bins that fall within the coverage area of the radar product are updated using the mosaic generation algorithm. The mosaic generation algorithm utilizes product data from all radars that provide overlapping coverage for the mosaic region covered by the new radar product to determine mosaic bin values.

When a new radar product is received, the radar product data must be incorporated into the WARP mosaic products within 5 seconds for 99.5% of the radar products. Any mosaic generation algorithm incorporated into the WARP system must be able to satisfy this requirement. System load analysis and simulation studies have been conducted by Harris Corp. to establish CPU loading budgets for new mosaic generation algorithms that will satisfy the update time requirements. During the algorithm development phase of this project, the processing load of the prototype mosaic generation algorithms has been monitored to ensure that the CPU loading budgets were not exceeded. These measurements were made using a set of test cases that impose a heavy CPU load on the system. The algorithm described in this paper performs within the CPU load budgets.

In relative terms, the CPU load of the prototype algorithm is approximately three times the load associated with a simple highest contributor algorithm.

3.0 MOSAIC GENERATION ALGORITHM

The prototype mosaic generation algorithm is a variant of the highest contributor algorithm which selects the highest contributor value, provided that there is either direct support from another contributor or the highest contributor value is not inconsistent with the data levels being reported by other contributing radars. The algorithm utilizes radar coverage maps as the basis for comparing data levels from contributing radar product bins. Radar coverage maps are radar and product type specific. These maps have the same spatial resolution and coverage areas as the corresponding radar products. The coverage maps are generated from terrain elevation data base information. For a description of the procedures used for generating radar coverage maps see Lang, et al (2003).

When a new radar product is received, a new value for each mosaic product bin that falls within the coverage area of the radar product is computed using the following sequence of steps which are described in the following sections:

1. Assemble contributing radar product bin data set.
2. Determine weather envelope elevation.
3. Use weather envelope elevation to classify contributors (primary/secondary).
4. Determine highest and second highest primary contributors.
5. Perform primary contributor test to select an initial mosaic bin value from primary contributor data.
6. Perform secondary contributor test to revise the mosaic bin value using secondary contributor data.

3.1 Contributing Radar Product Bin Data Set

The data set used in the following steps to select the mosaic bin value includes the following information for each of the contributing radar product bins:

1. Radar product bin value
2. Radar product bin support level
3. Minimum radar coverage elevation
4. Radar product bin update time

The mosaic bin will be assigned one of the radar product bin values.

In the following tests, the highest contributor bin value is compared to the support level information for the other contributors to determine if the highest contributor value should be accepted or rejected. Using the support level information instead of the raw bin values for validating the highest contributor value compensates for the inexact space-time correlation of inputs from multiple radars that is inherent in the mosaic generation process. The support level value for a radar product bin is the maximum data level of all the radar product bins whose center points fall within a specified radius of the radar product bin. The support level computed for a radar product bin can therefore be greater than the radar product bin value.

The minimum radar coverage elevation is the corresponding composite reflectivity product radar coverage map bin value. The elevation coverage range of the composite reflectivity product data is nominally from the surface to 60,000 feet. However, the actual elevation coverage range of a WSR-88D radar varies throughout the coverage area of the radar due to the effects of earth curvature and terrain blockage. The composite reflectivity product coverage map specifies the lowest elevation actually scanned by the radar for each radar product bin. The minimum radar coverage elevation takes into account the effects of earth curvature, standard atmospheric refraction, and terrain blockage.

The radar product bin update time is the time the corresponding radar product is received by the WARP system. The bin update time information is used in the secondary contributor test.

3.2 Determination of Weather Envelope Elevation

The weather envelope elevation is determined from the support level and minimum radar coverage elevation data. The weather envelope elevation is somewhat analogous to an echo tops elevation. Where the echo tops elevation specifies the maximum elevation where radar returns above a threshold level have been detected, the weather envelope elevation specifies the elevation above which there appears to be no weather. Where the echo tops elevation is determined from non-zero returns, the weather envelope elevation is determined from zero-valued returns. It is based on the assumption that weather located within elevation ranges actually scanned by a radar can be seen by (i.e. are not invisible to) the WSR-88D radars. The weather envelope elevation for a mosaic bin is equal to the lowest minimum radar coverage elevation of the subset of radar product bins having a support level of zero (the radars that see nothing). Stated another way, it is the minimum coverage elevation of the radar with the best view that sees nothing.

3.3 Classification of Contributors

The weather envelope elevation for the mosaic bin is used to classify the contributing radar product bins as either primary or secondary contributors. Contributing bins with minimum radar coverage elevations less than or equal to the weather envelope elevation are classified as primary contributors. Contributing bins with minimum radar coverage elevations greater than the weather envelope elevation are classified as secondary contributors.

3.4 Highest/Second-Highest Primary Contributors

The highest primary contributor value is the highest radar product bin value from the subset of contributing bins classified as primary contributors. The remaining primary contributor bins are used to determine the second highest primary contributor value and the highest contributor support level. The second highest primary contributor value is the highest radar product bin value from the remaining primary contributor bins. The highest contributor support level is the highest support level from the remaining primary contributor bins.

3.5 Primary Contributor Tests

One of two tests is used to select either the highest or second highest primary contributor value as the mosaic bin value. The test used depends on the value of the highest primary contributor support level. If the highest primary contributor support level is greater than zero (at least two primary contributors see something), the Case 1 primary contributor test is performed. If the highest primary contributor support level is zero (only one primary contributor sees something), the Case 2 primary contributor test is performed.

3.5.1 Case 1 Primary Contributor Test

This test first computes a support criteria based on radar coverage elevations for the highest contributor and highest support level contributor, and then uses the support criteria to select either the highest or second highest primary contributor value as the mosaic bin value.

The weather envelope elevation and the minimum radar coverage elevations for the highest primary contributor and the highest support level contributor are used to compute a coverage ratio within the weather envelope between the highest primary contributor and the highest support level contributor. The coverage ratio is a measure of the comparative view that the two contributors have inside the weather envelope. The coverage ratio is used to determine the support criteria for the highest contributor value. Higher coverage ratios (highest contributor has the better view) have relaxed (larger) support criteria values. Lower coverage ratios (highest support level contributor has the better view) have tighter (smaller) support criteria values.

The difference between the highest contributor value and the highest support level is compared to the support criteria value. If the difference is less than or equal to the support criteria value, the mosaic bin is assigned the highest primary contributor value (the support criteria has been satisfied). If the difference is greater than the support criteria value, the mosaic bin is assigned the second highest primary contributor value (the support criteria has not been satisfied).

3.5.2 Case 2 Primary Contributor Test

When this test is performed, there are only two primary contributors. The contributor with the best view sees something (the highest contributor), and the contributor with the next best view sees nothing (second highest contributor). A series of four validity checks are performed to determine whether the highest contributor value should be used. These checks, which are based on the minimum radar coverage elevations of the two contributors, are performed in the sequence described below until one of the checks determines the mosaic bin value. If none of the checks selects the mosaic bin value, the highest contributor value is rejected and the mosaic bin is set to zero. The four validity checks are:

1. Boundary Layer Check - If the minimum coverage elevation of the second highest contributor is close to the ground, reject the highest contributor value (the mosaic bin value is set to zero).
2. Overlapping Coverage Check - If the minimum coverage elevations of the two contributors are nearly equal, reject the highest contributor value (the mosaic bin value is set to zero).
3. Non-overlapping Coverage Check - If there is a large difference between the minimum coverage elevations of the two contributors, accept the highest contributor value.
4. If the vertical gradient (Dbz/km) computed from the differences in data values and coverage elevations of the two contributors is not excessive, accept the highest contributor value.

3.6 Secondary Contributor Test

Once a value has been selected for the mosaic bin by one of the primary contributor tests, the secondary contributor data is compared to the mosaic bin value selected by the primary contributor test. The secondary contributor data may represent rapidly developing weather that should be included in the mosaic product.

In order for a secondary contributor to be considered, it must satisfy the following conditions:

1. Bin value must be greater than the mosaic bin value.
2. Bin update time must be more recent than the update time of the radar product bin currently selected for the mosaic bin.
3. Minimum radar coverage elevation of the bin must not be too high.

If these conditions are satisfied, the reflectivity growth rate (Dbz/minute) is computed from the data level and bin update time information. If the growth rate is not excessive, the mosaic bin is assigned the value of the secondary contributor bin.

Each of the secondary contributor bins are subjected to this test. At the conclusion of this test, the mosaic product array bin is set to the mosaic bin value.

3.6 Adaptation Data

It is noteworthy that during the evaluation of the prototype algorithm, seasonal or geographic adjustment of the adaptable parameters that control the algorithm was not required to achieve the desired performance levels. The mosaic products used for the algorithm performance evaluation described in section 4.0, and the examples shown in Section 5.0 were all generated using the same set of adaptable parameters.

4.0 ALGORITHM PERFORMANCE EVALUATION

Test case product sets were collected in order to evaluate the performance of the prototype mosaic generation algorithms. Each product set consists of at least 30 minutes of radar product data from approximately 40 WSR-88D radars with overlapping coverage in an area of interest. The data sets also include the IR and visible satellite image products that fall within the data collection time interval. While these test cases focus primarily on weather scenarios that have the highest potential impact on flight control operations (severe weather in high traffic areas), test cases have also been included for a variety of synoptic weather scenarios collected in different seasons, and in all regions of the US. To date, over 100 test case product sets have been collected and evaluated.

For each test case, the radar product data was used to generate a sequence of highest contributor mosaic products and prototype algorithm mosaic products. From these sequences the mosaic products closest in time to the satellite image products were selected for evaluation. The satellite data was used to assess the type of returns being removed by the prototype algorithm. Product loops of the highest contributor mosaic products were also used in the analysis to asses the relative motion and stability of product features being removed by the prototype algorithm.

The test case mosaic products and evaluation products were made available to FAA evaluators during the algorithm development effort via a website.

5.0 RADAR MOSAIC TEST CASE EXAMPLES

Figures 1-12 illustrate the prototype algorithm performance for a representative set of the test cases described in section 4.0. In each of these Figures, the frame on the left is the highest contributor mosaic product; the frame in the middle is the prototype algorithm mosaic product; the frame on the right is the data that has been removed by the prototype algorithm (i.e. the difference between the highest contributor and prototype algorithm mosaic products). The Figure titles indicate the test case number, the geographic region and the data collection date.

Figures 1-4 are from the Northeast corridor region, an area of the US where weather has the most disruptive effects on air traffic control operations. Figures 5-9 are from the Southeast region, an area which experiences a great deal of severe weather. Figure 10-11 are from the central plains region where radars are more widely spaced. Figure 12 is from the Rocky Mountain region where terrain blockage limits the coverage for many WSR-88D radars.

Most of the test cases shown are summer convective weather scenarios. There are a several fall and winter weather test cases (Figures 4, 6, 7, 10). Figure 5 is a test case where there are virtually no weather returns, but excessive non-meteorological returns.

Many of these test cases contain moderate to significant AP returns. Several (Figures 5, 6, 7) contain sunrise spikes. Figure 2 includes very severe "interference" returns caused by a hardware failure at the Sterling, VA WSR-88D.

In comparing the mosaic products with the corresponding satellite images, there was a high degree of correlation between returns retained by the prototype algorithm and the features in the satellite images. Similarly, the data removed by the algorithm showed a high degree of correlation with the low intensity areas of the satellite images. The prototype algorithm has demonstrated consistent performance in removing non-meteorological returns and preserving weather returns across all of the test cases evaluated to date.

6.0 SUMMARY

The results of our initial evaluation of the prototype mosaic generation algorithm indicates that it performs well for all of the test cases used in the evaluation. The algorithm is effective in removing a high percentage of the non-meteorological returns, while removing a very small percentage of the weather returns. The algorithm is particularly effective in removing the highest amplitude non-meteorological returns, while preserving the highest amplitude weather returns. A formal validation of the algorithm performance by the FAA is currently being planned.

7.0 REFERENCES

Lang, J., Sutker, B., Chase, G and Zhang, J, 2002: Using Terrain Elevation Information to Improve the Quality of Radar Mosaic Products. Preprints 19th International Conference on IIPS, Long Beach, CA, Amer. Meteor. Soc., paper 14.14.

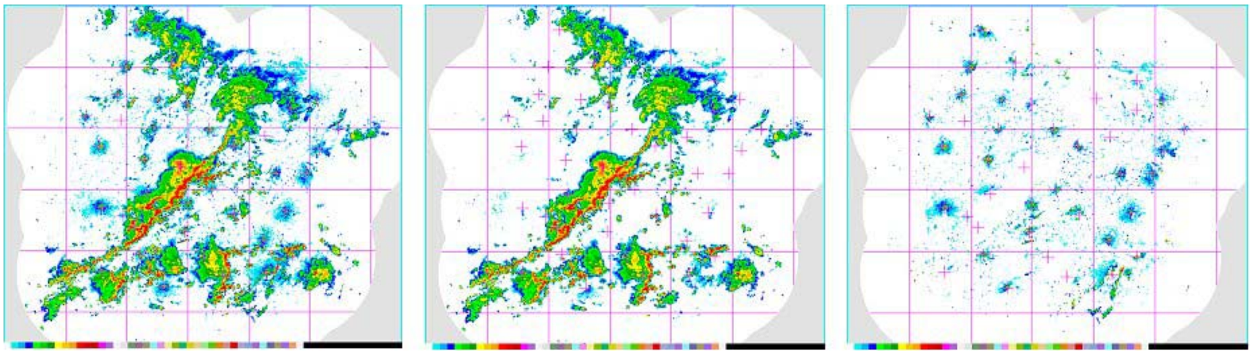

Figure 1. Case 49, Northeast Corridor Region, July 10, 2003

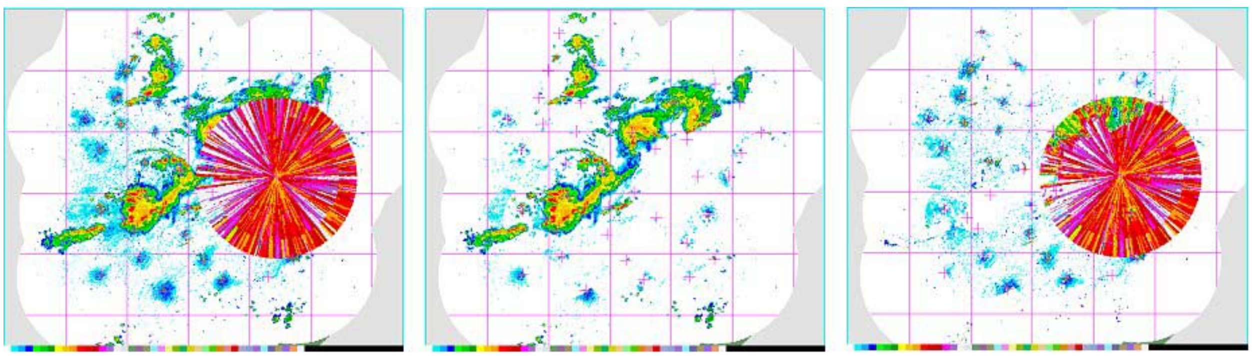

Figure 2. Case 54, Northeast Corridor Region, July 21, 2003

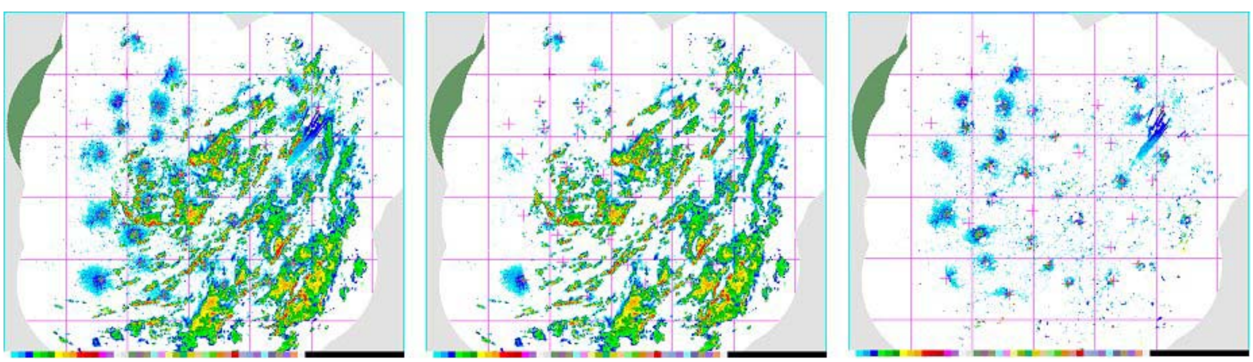

Figure 3. Case 65, Northeast Corridor Region, July 23, 2003

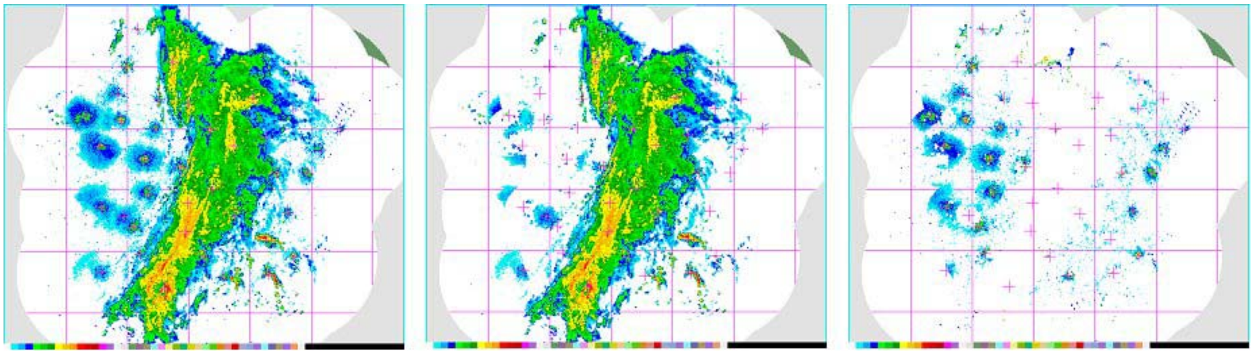

Figure 4. Case 99, Northeast Corridor Region, September 22, 2003

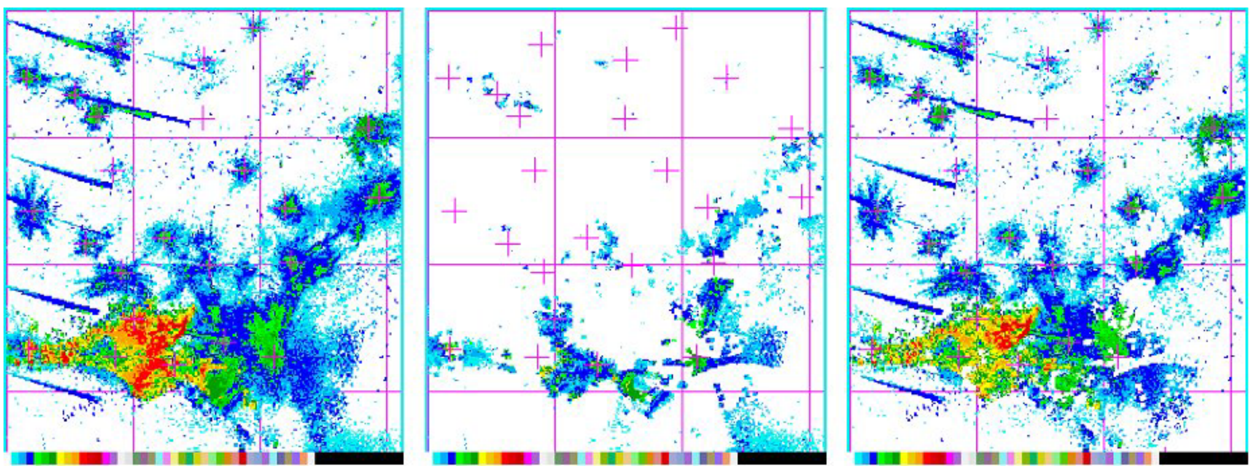

Figure 5. Case 13, Southeast Region, October 18, 2002

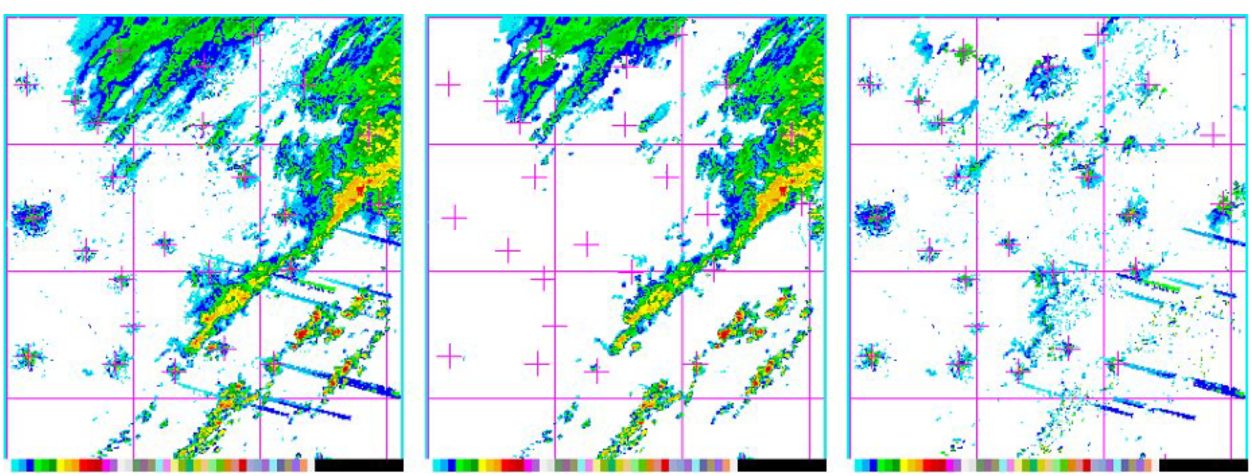

Figure 6. Case 19, Southeast Region, February 10, 2003

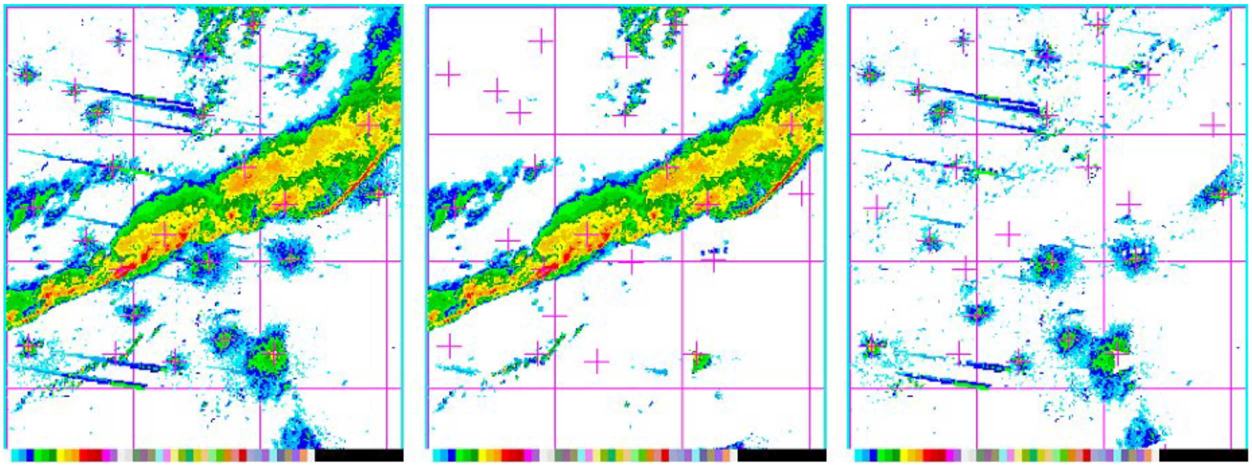

Figure 7. Case 22, Southeast Region, November 2, 2002

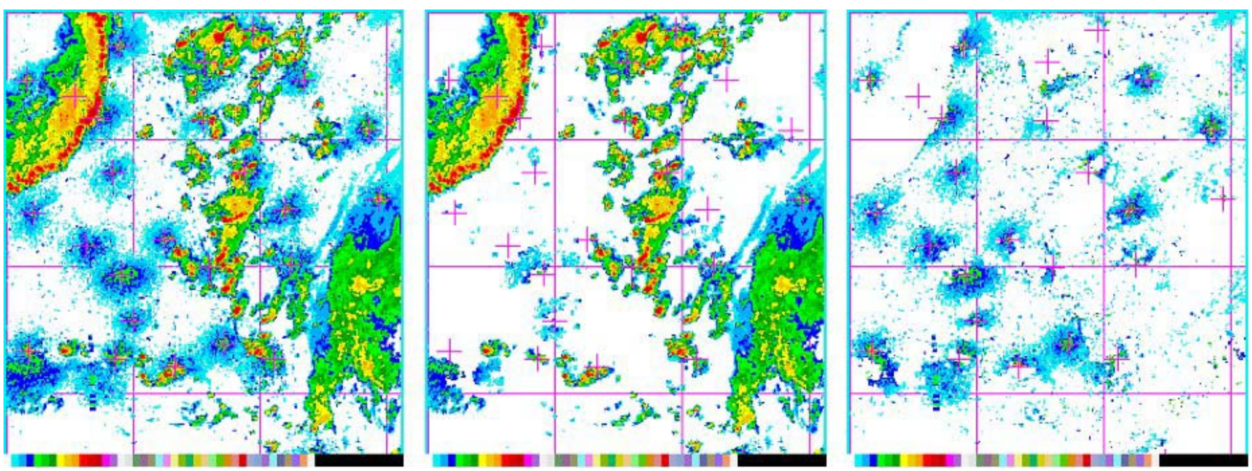

Figure 8. Case 23, Southeast Region, May 1, 2003

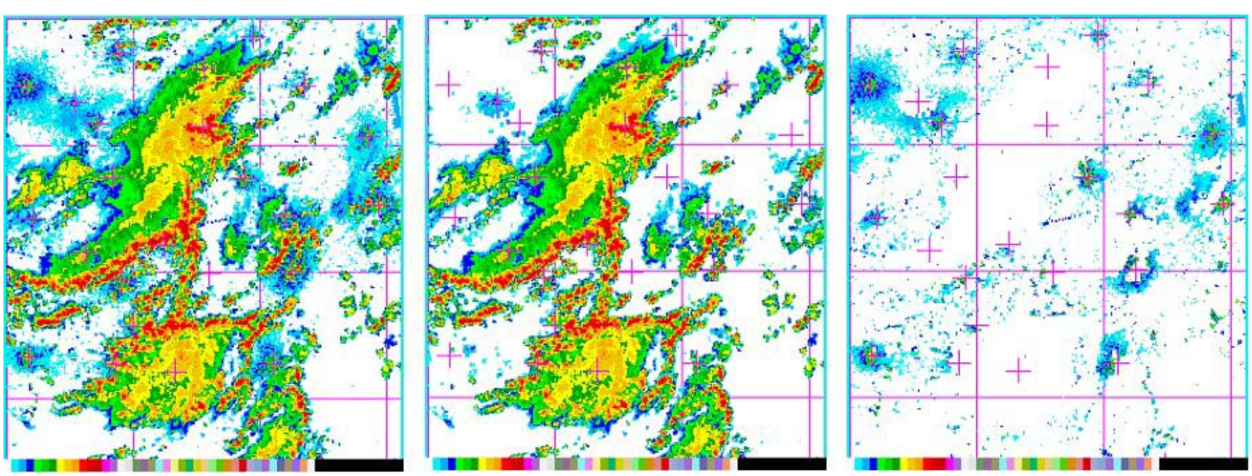

Figure 9. Case 68, Southeast Region, July 22, 03

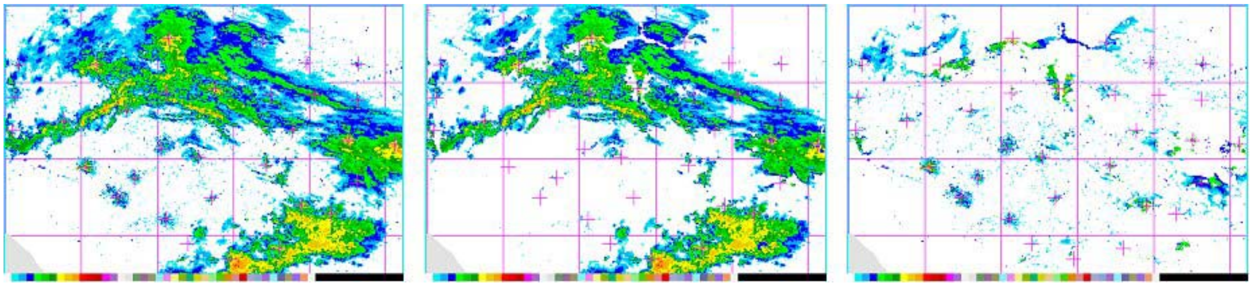

Figure 10. Case 2, Central Plains Region, February 14, 2003

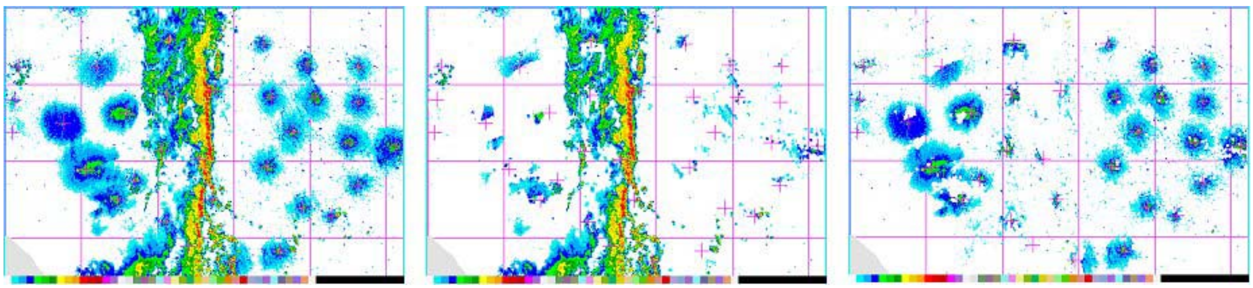

Figure 11. Case 96, Central Plains Region, September 11, 2003

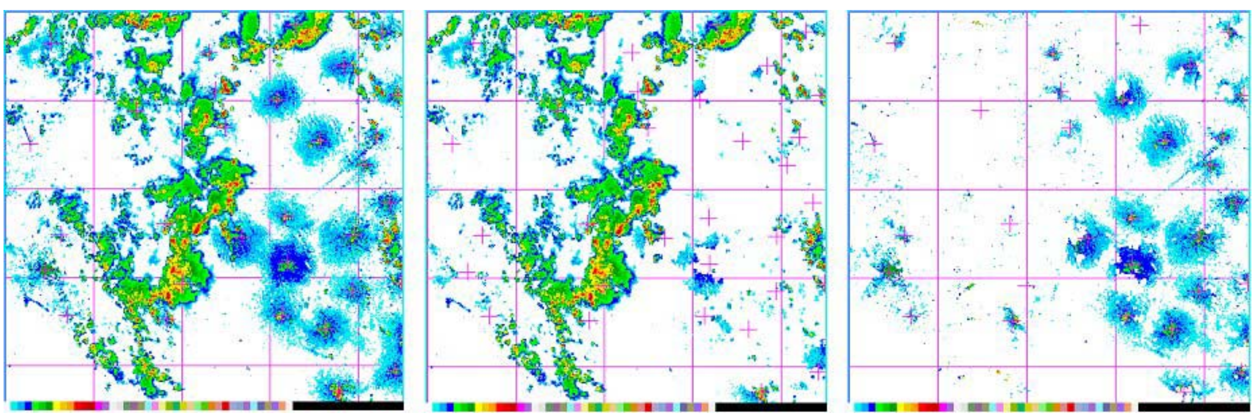

Figure 12. Case 52, Rocky Mountain Region, June 16, 2003