2.5 NEW ROTATION TRACK QUALITY CONTROL TECHNIQUES FOR A MULTI-YEAR CLIMATOLOGY

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ABSTRACT

Both the location and intensity of mesocyclone circulations can be monitored in real-time by accumulating regions of high azimuthal shear at low (0-3 km AGL) and mid-levels (3-6 km AGL) over time. These azimuthal shear values are calculated in a noise-tolerant manner by fitting to a plane the Doppler velocity observations in the neighborhood of a pulse volume and then finding the slope of that plane. Non-meteorological signatures caused by poor velocity dealiasing, ground clutter, radar test patterns and spurious shear values often plague rotation tracks created in this manner, however, inhibiting their usefulness.

In order to improve the quality of these fields for real-time use by emergency responders and warning decision-makers, and for an accumulated multi-year climatology as part of the Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS) project, new quality control measures have been implemented. These measures - new dealiasing strategies, filtering based on reflectivity data, hysteresis segmentation, and Multiple Hypothesis Tracking (MHT) techniques - remove nearly all non-meteorological contaminants and successfully isolate the rotation tracks. Each quality control measure will be discussed and the specific impacts of each will be shown.

1. INTRODUCTION

The National Severe Storms Laboratory (NSSL) creates products called “rotation tracks” which depict the paths and intensities of mesocyclone circulations as seen by radar using the Warning Decision Support System – Integrated Information (WDSS-II; Lakshmanan et al. 2007b) suite of programs. These fields are created by calculating azimuthal shear fields and then accumulating the maximum values in those gridded fields over time onto one accumulated grid. See Figure 1 for an example.

These tracks can aid in the interpretation and analysis of velocity fields. They also provide information about the spatial extent and strength of mesocyclone signatures over time. These products have enormous data mining potential and can be used as forecaster guidance, aids for post-storm damage surveys, and even as tools to deliver assistance after tornado events (NOAA/NSSL 2011). They are plagued by non-meteorological signatures, however, caused by poor velocity dealiasing, ground clutter, radar test patterns, and spurious shear values. These non-meteorological artifacts can make the tracks difficult, if not impossible, to interpret meaningfully. An example is shown in Figure 2.

One of the goals of the Multi-Year Reanalysis of Remotely Sensed Storms (MYRORSS) project, a cooperative effort between National Oceanic and Atmospheric Administration’s (NOAA) NSSL and the National Climatic Data Center (NCDC), is to create a CONUS-wide climatology of low and mid level rotation track fields for the lifetime of the Weather Surveillance Radar 1988-Doppler (WSR-88D) network.

Before this climatology can begin processing, however, the quality of the rotation track fields must be greatly improved. This paper addresses the velocity dealiasing techniques, filtering based on reflectivity data, hysteresis segmentation, and Multiple

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Hypothesis Tracking (MHT) techniques developed to isolate the rotation tracks from non-meteorological signatures in real-time and for the MYRORSS climatology. Explanations and specific impacts of each technique will be provided.

2. TRADITIONAL ROTATION TRACK PROCESSING

To produce rotation tracks, radial velocity data are first dealiased using the default WSR-88D dealiasing algorithm developed by Eilts and Smith (1990). A quality control neural network (Lakshmanan et al. 2007a, Lakshmanan et al. 2010) then removes echoes in the reflectivity field produced by non-meteorological phenomena (anomalous propagation, ground clutter, etc.) to produce the ReflectivityQC field.

ReflectivityQC and the dealiased velocity field are then employed by the shear estimation algorithm of Smith and Elmore (2004) to compute the azimuthal shear. Using digital elevation model (DEM) data to determine the height of each grid point above the ground, 2-D maximum azimuthal shear fields within low (0-3 km) and mid (3-6 km) level layers above ground level (AGL) are also calculated.

The intelligent agent formulation developed by Lakshmanan et al. (2006) is then used to merge these single-radar 2-D maximum azimuthal shear fields into a Cartesian multi-radar grid. The formulation accounts for varying radar beam geometry with range, vertical gaps between radar scans, and other issues. The maximum values of each pixel in the merged multi-radar grid over a given time interval (typically 60-120 minutes) then form the swaths of merged maximum azimuthal shear known as rotation tracks. Figure 3 provides a flow chart showing the algorithms and fields used to create rotation tracks.

3. NEW QUALITY CONTROL TECHNIQUES

In an effort to improve the usefulness of these products, new quality control techniques were tested and developed based on their performances in 16 different cases. These cases ranged in intensity from weak mesocyclones associated with non-tornadic storms to extremely intense mesocyclones associated with violent tornadoes. The techniques developed are discussed in the following sections.

3.1. *New velocity dealiasing strategy*

The default WSR-88D real-time dealiasing algorithm of Eilts and Smith (1990) was the traditional method used to dealiase the radial velocity data when processing rotation track products. In the cases evaluated for this study, this dealiasing method performed relatively poorly, especially in high shear environments. Spikes of high shear values along radials associated with dealiasing problems (shown in Figure 4) plagued the rotation track products.

In an effort to improve the quality of the dealiased velocity fields, vertical profiles of the horizontal wind at each radar site derived from the 20-km RUC (Rapid Update Cycle; Benjamin et al. 2004) were used as first-guess environmental winds. This improved the quality of the dealiased fields, but the algorithm still performed poorly in many cases.

The 2-D velocity dealiasing algorithm developed by Jing and Weiner (1993) performed much better qualitatively on the cases evaluated. The method solves a linear system of equations that minimizes gate-to-gate shear in isolate 2-D regions. Aliasing-induced discontinuity information is then used to find correction values for each gate by solving a 2-D least-mean-squares problem. Incorporating the 20-km RUC first-guess wind profiles improved the algorithm's performance further. A representative example of how the dealiased velocity fields and corresponding azimuthal shear fields associated with the different algorithms is shown in Figure 4.

3.2. *Filtering based on ReflectivityQC*

When processing the 2-D maximum azimuthal shear fields, all shear data not co-located with a given ReflectivityQC value is removed so that only shear co-located with storm regions are retained. Traditionally, the ReflectivityQC threshold used has been 20 dBZ. Using this threshold, however, allowed a great deal of non-meteorological shear to remain in the rotation track fields, particularly near radar sites (see Figure 5).

To remove some of these clear-air and non-meteorological shear signatures, the ReflectivityQC threshold needed to be raised. In order to retain the important shear signatures in low ReflectivityQC hook echo regions associated with mesocyclones, a 5x5 dilation filter (Lakshmanan 2012) was implemented on the ReflectivityQC field before using it to define storm regions. Essentially, this operation assigns the maximum reflectivity value in a 5x5 moving window to each pixel, effectively expanding the areas of high dBZ values. Once operation is performed, using a higher Reflectivity threshold of 40 dBZ maintains important meteorological shear while also removing many of the clear air shear signatures.

An azimuthal shear range-correction algorithm (Newman et al. 2012) designed to correct for range degradation due to radar beam widening is also implemented. The algorithm identifies significant circulations using reflectivity and azimuthal shear criteria. Then, it plugs each circulation's shear diameter, maximum measured velocity, and range from the radar into the appropriate regression equation to calculate new azimuthal shear values. This step in rotation track processing is critical to successfully merging azimuthal shear values from multiple radars onto a multi-radar grid.

3.3. *Hysteresis segmentation*

Once the quality of the 2-D maximum azimuthal shear fields is much improved by the new velocity dealiasing strategy and ReflectivityQC thresholds, it is then possible to identify and isolate clusters of high azimuthal shear values in each time step. This is done using hysteresis segmentation (Jain 1989). In this application, two different data thresholds are established and clusters are defined as contiguous pixels with values greater than the lower data thresholds that contain at least one pixel with a data value above the higher threshold. Through qualitative experimentation, it was found that low and high data thresholds of 0.002 s^{-1} and 0.005 s^{-1}, respectively, and a minimum size threshold of 25 pixels performed well at isolating clusters of high azimuthal shear. A representative example of the impact of hysteresis segmentation is shown in Figure 6.

It was observed that any remaining non-meteorological clusters were composed of uniform distributions of very high values while meteorological clusters were typically composed of unimodal distributions of much lower values. Representative examples of both are shown in Figure 7. To take advantage of this information, a threshold was set to remove any clusters composed of more than 80% pixels with data of values of at least 0.02 s^{-1}.

All pixels in the maximum 2-D azimuthal shear fields not associated with identified clusters are then removed. These much sparser fields are then accumulated over time to produce rotation tracks associated. The rotation tracks themselves are now more isolated since low background azimuthal shear values are removed (see Figure 7).

3.4. *Multiple hypothesis tracking (MHT)*

After clusters of high azimuthal shear are identified in each time step, it is then possible to associate those clusters in time. Clusters associated with mesocyclone circulations typically persist for many time steps while non-meteorological clusters appear only sporadically. Therefore, by removing clusters existing in only one step we can further isolate the rotation tracks. Multiple hypothesis tracking (MHT; Cox and Hingorani 1996) techniques are employed to perform this task.

The MHT algorithm has only recently been adopted by the meteorology community (Root et al. 2011). It considers time associations globally and makes association decisions that can be deferred until more information is available. If the algorithm is unsure whether to associate a given track with cluster A or cluster B at a given time step, for example, it can create two hypotheses. Both possibilities are then propagated forward in time to when enough information should be available to determine which association is most likely. A helpful diagram is shown in Figure 8. Clusters not meeting the minimum longevity threshold (two time steps or roughly 10 minutes) are then retroactively pruned so they do not appear in the rotation track fields.

To determine the optimal associations, an association cost matrix is constructed so that each entry corresponds to the cost of matching a cluster at one time step with a cluster in the next time step. Costs are based on cluster sizes, ages, proximities to clusters in previous time steps and other characteristics. The associations with the lowest costs are then made. Enumeration of all hypothesis matrices to find the lower costs can increase exponentially with each additional time step, so a technique based on Murty (1968) is used to prune the set to retain only the k-best associations at each time step. For more details on MHT, the reader is referred to Lakshmanan et al. (2012). Figure 9 shows a representative example of the impact of MHT.

4. RESULTS

Based on their performances in the 16 cases used for the study, each of the new quality control techniques qualitatively improves the rotation track fields. The velocity dealiasing technique of Jing and Weiner (1993) with the 20-km first-guess environmental wind field performs much better qualitatively at correctly dealiasing velocity than the Eilts and Smith (1990) method. It eliminates nearly all the noisy, high azimuthal shear values associated with dealiasing issues, making the rotation track fields easier to interpret.

Raising the ReflectivityQC threshold from 20 to 40 dBZ (after the implementation of the 5x5 dilation filter) helps to remove many of the clear air signatures near radar sites from the rotation track fields. Hysteresis segmentation is then used to identify and isolate clusters of high azimuthal shear in each time step of the 2-D maximum azimuthal shear fields. Since only the identified clusters are accumulated over time rather than all azimuthal shear values, the corresponding rotation track fields are much clear and easier to interpret. Finally, MHT technique are used to remove any clusters present in only one time step, further isolating the long-lived rotation tracks from any remaining non-meteorological artifacts.

Figure 10 highlights the differences between the original rotation track products and the same products after implementing the new quality control techniques.

5. CONCLUSIONS

NSSL rotation track products are valuable tools in disaster response situations. They allow users to assess the spatial extent and relative intensities of mesocyclone circulations as seen by radar over time. While these products are useful, they are contaminated by non-meteorologist signatures associated with poor velocity dealiasing, ground clutter, etc. In many cases, these signatures make the rotation tracks nearly impossible to interpret. To improve the quality of these products both in real-time and for a forthcoming MYRORSS rotation track climatology, quality control techniques have been developed and implemented.

These techniques – a new velocity dealiasing strategy, filtering based on ReflectivityQC, hysteresis segmentation and MHT techniques – significantly improve the quality and ease of interpretation of the rotation track products. With these improvements made, the MYRORSS rotation track climatology will begin processing in the near future. For a more thorough explanation of the quality control techniques, the reader is referred to Miller et al. (2012).

6. REFERENCES

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FIGURES

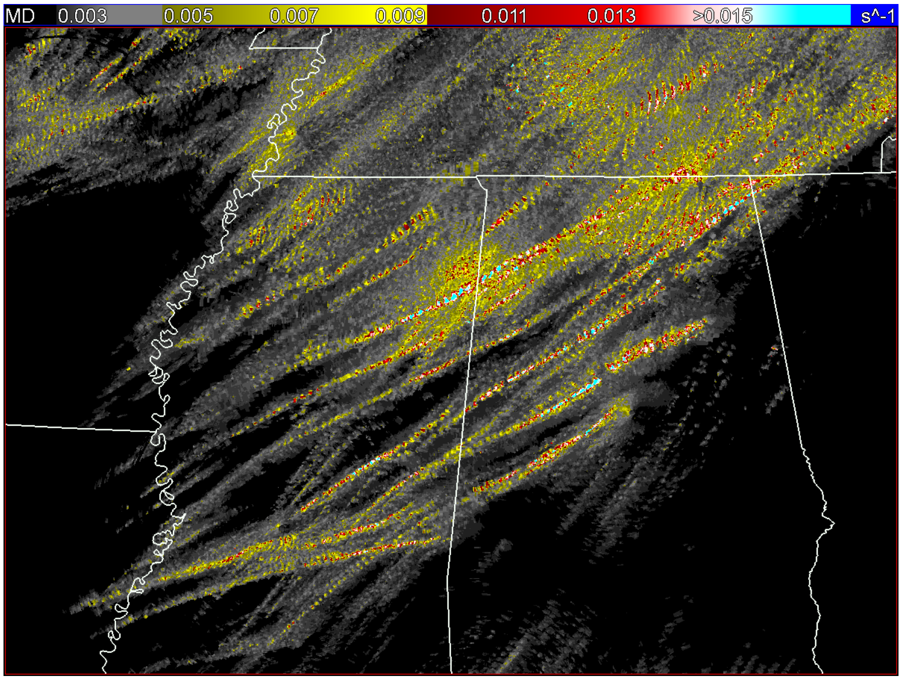

Figure 1: Low level (0-3 km AGL) rotation tracks associated with 27 April 2011 tornado outbreak. These tracks correspond to storms between 16 UTC on 27 April and 00 UTC on 28 April.

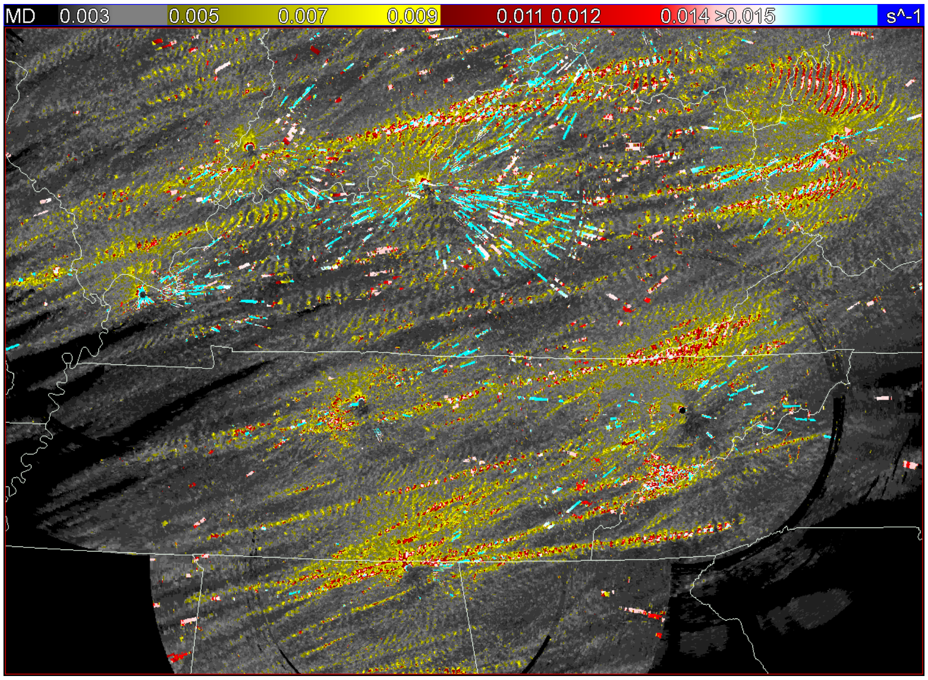

Figure 2: Low level (0-3 km AGL) rotation tracks associated with 2 March 2012 tornado outbreak. Note the contamination by non-meteorological signatures that make interpretation difficult.

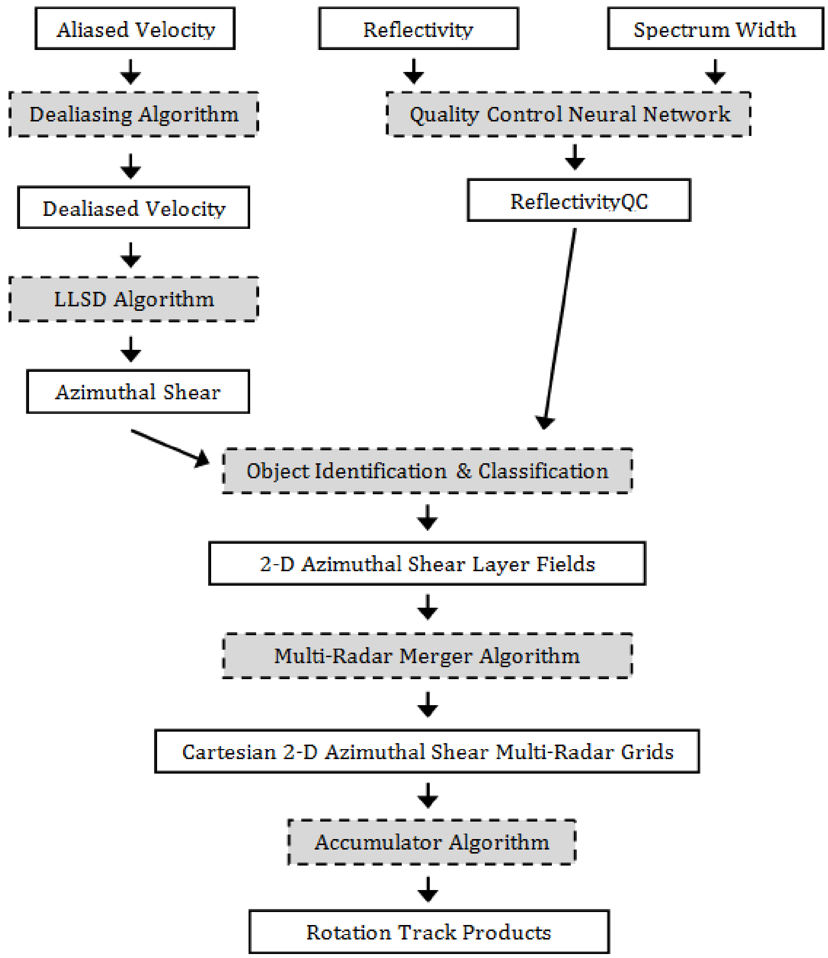

Figure 3: Flow chart showing the traditional method of processing rotation track products. Algorithms are shown as grey dashed boxes and data fields are shown as solid white boxes.

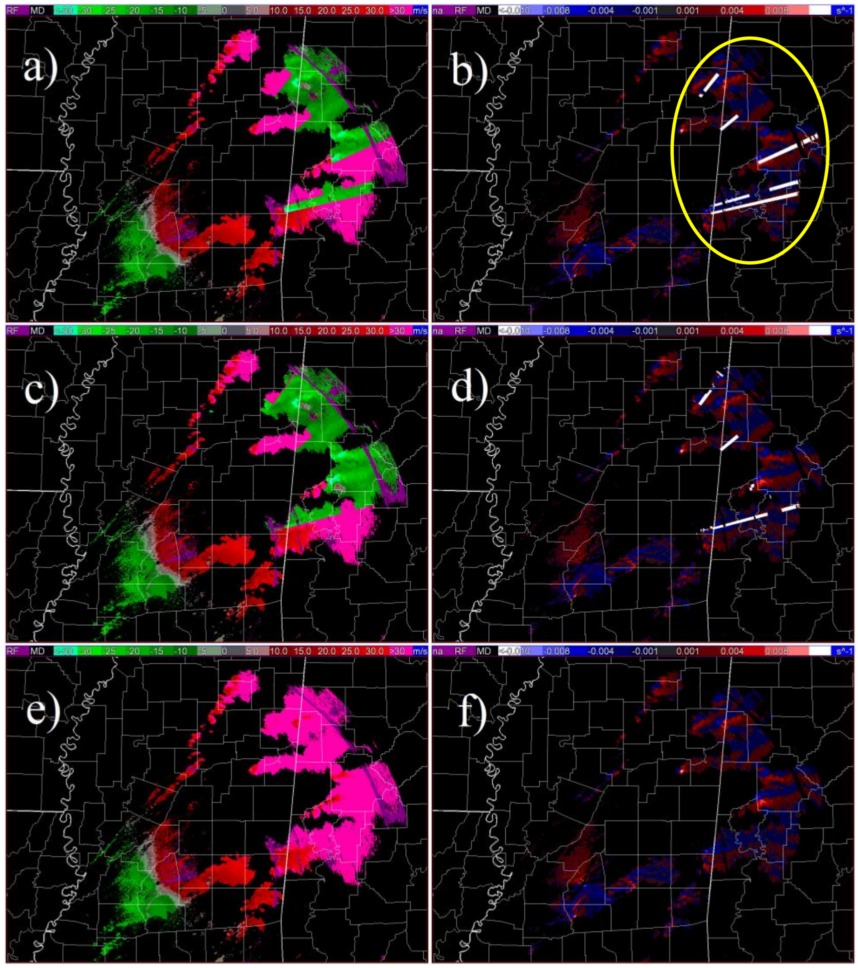

Figure 4: Dealiased velocity and corresponding azimuthal shear fields from KDGX on 27 April 2011 at 2151 UTC processed using different velocity dealiasing methods. (a) Radial velocity associated with the Eilts and Smith (1990) dealiasing method. (b) Azimuthal shear field associated with (a). The yellow circle highlights spikes of high azimuthal shear values associated with poor dealiasing. (c) Radial velocity dealiased using the Eilts and Smith (1990) using a first-guess environmental wind field from the 20-km RUC at the nearest grid point. (d) Azimuthal shear field associated with (c). (e) Radial velocity dealiased using the Jing and Weiner (1993) algorithm with the first-guess environmental wind field from the 20-km RUC. (f) Azimuthal shear associated with (e).

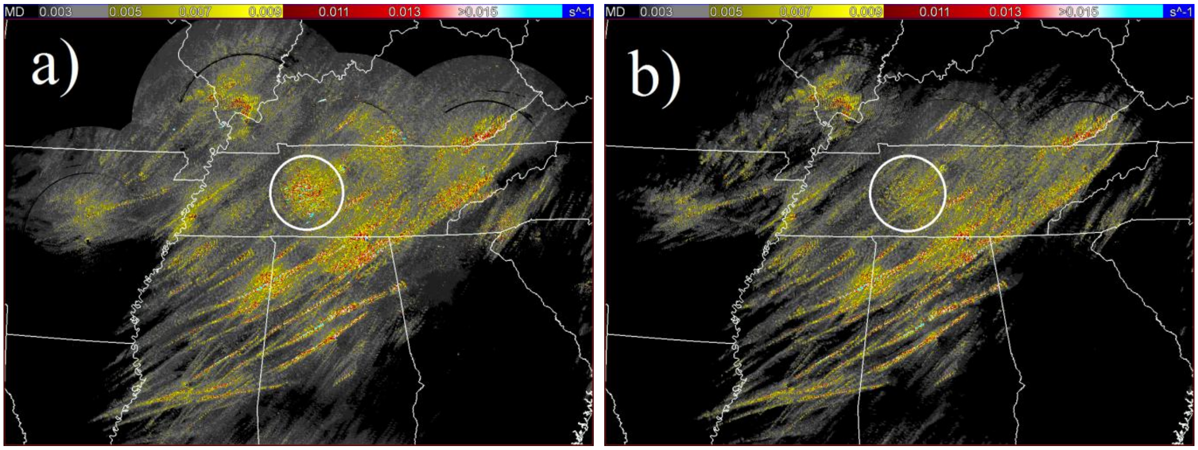

Figure 5: Low-level (0-3 km AGL) rotation tracks associated with the 27 April 2011 outbreak. (a) Rotation tracks created using the 20 dBZ ReflectivityQC threshold. (b) The same tracks created using the 40 dBZ ReflectivityQC threshold with the 5x5 dilation filter. The white circle highlights an area contaminated by clear air shear signatures. Note that the contamination is lessened in (b).

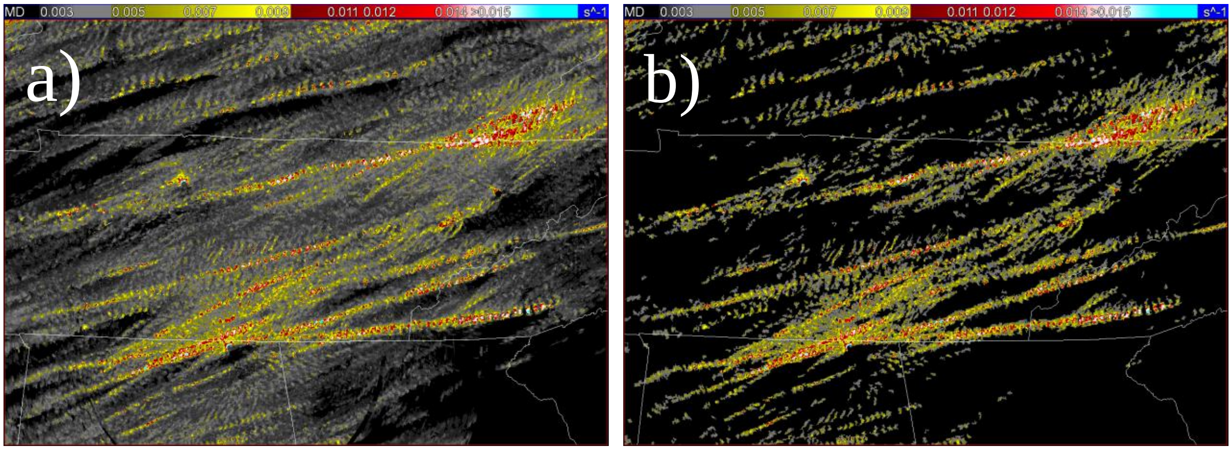

Figure 6: Low-level (0-3 km AGL) rotation track products associated with the 2 March 2012 outbreak. (a) Rotation track products incorporating new velocity dealiasing and ReflectivityQC thresholds, but *without* hysteresis segmentation. (b) The same rotation tracks *with* hysteresis segmentation.

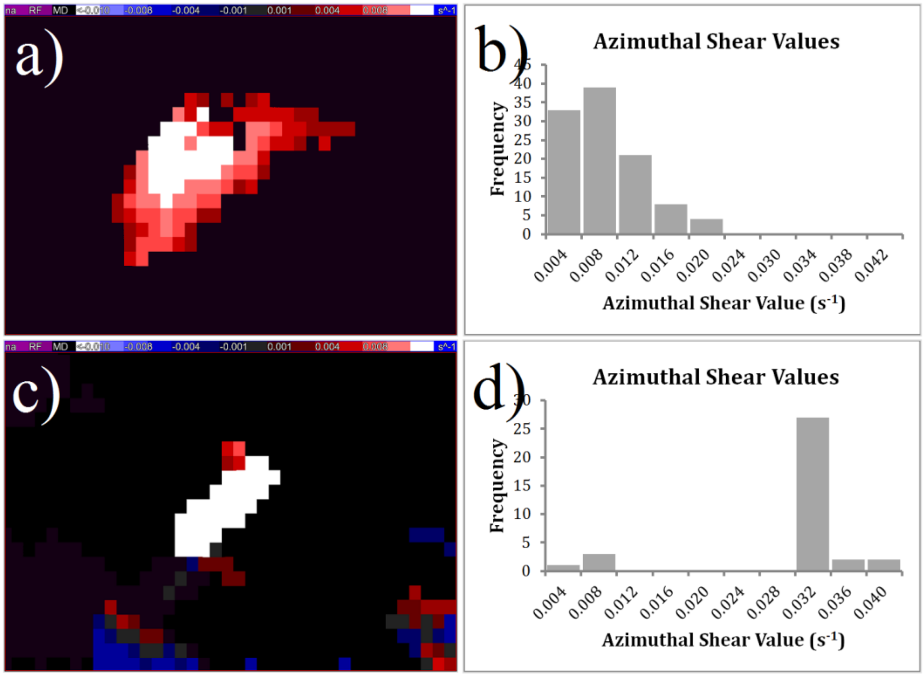

Figure 7: (a) A cluster of high azimuthal shear associated with a mesocyclone. (b) The data distribution associated with the mesocyclone cluster. (c) A cluster of high azimuthal shear associated with a non-meteorological artifact caused by poor velocity dealiasing. (d) The data distribution associated with the non-meteorological artifact signature.

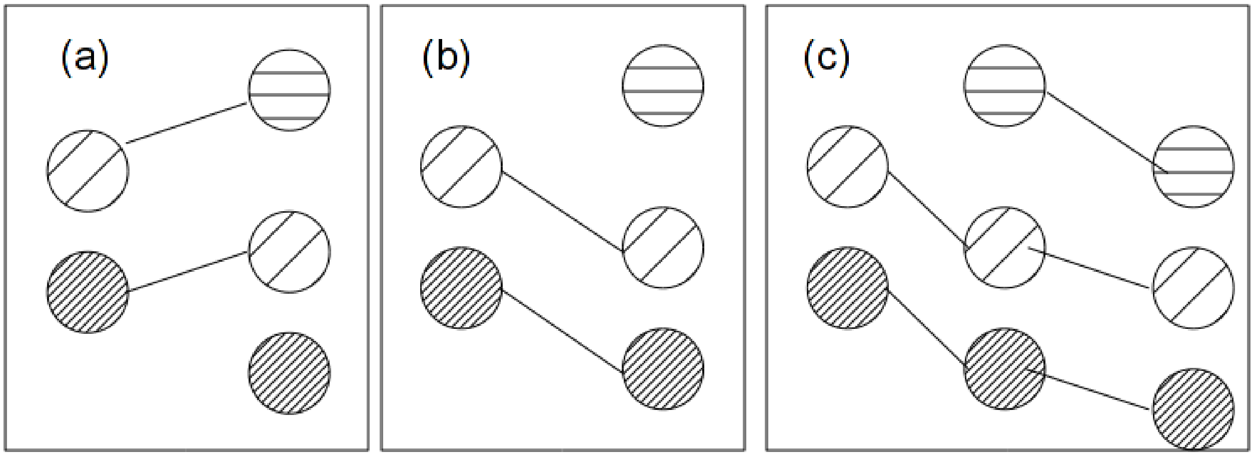

Figure 8: Figure from Lakshmanan et al. (2012) showing why the MHT algorithm is needed. Clusters that should be associated in time have the same shading. Associations are denoted by solid lines. (a) The optimal associations between two objects in the first frame and three objects in the second frame. (b) The second best associations. (c) Once the third frame is available, it becomes clear that the second hypothesis was the better choice.

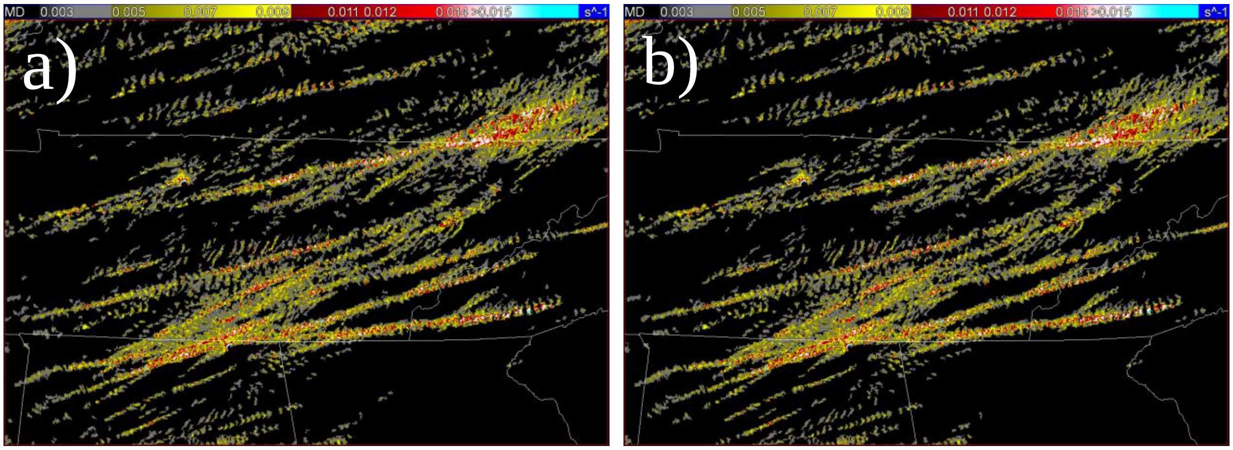

Figure 9: Low-level (0-3 km AGL) rotation tracks associated with the 2 March 2012 outbreak. (a) Rotation tracks created using all the quality control techniques but *without* MHT. (b) The same rotation track products created *with* MHT. The differences are not striking, but it is apparent that some isolated clusters are removed using MHT.

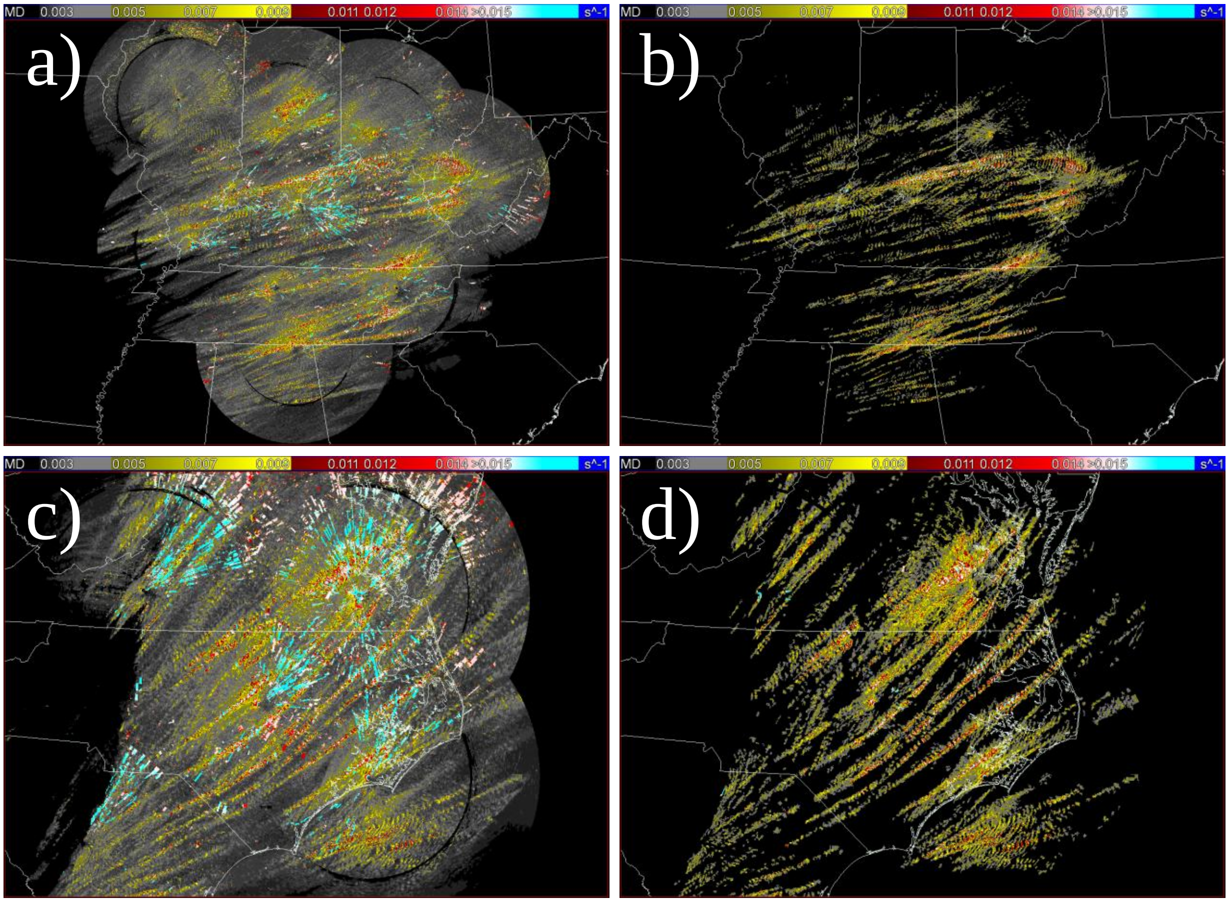

Figure 10: The impact of the rotation track quality control techniques on two different cases. (a) Low-level (0-3 km AGL) rotation track products associated with the 2 March 2012 outbreak before quality control. (b) The same rotation track products after quality control techniques were implemented. (c) Low-level (0-3 km AGL) rotation track products associated with the 16 April 2011 outbreak without before quality control. (d) The same rotation track products after quality control.