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PERFORMANCE CHARACTERISTICS OF AN ALGORITHM USED TO REMOVE ANOMALOUS PROPAGATION FROM THE NEXRAD DATA*†

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1. INTRODUCTION

An important limitation of precipitation sensors is contamination from ground clutter targets under conditions of anomalous propagation (AP) (Wéber, et al., 1993). This problem can be mitigated significantly by high–pass clutter filters such as those used by the Terminal Doppler Weather Radar (TDWR) (Michelson et al., 1990) and Next Generation Weather Radar (NEXRAD) systems (Evans, 1983).

However, the typical operating mode of the NEXRAD is to only apply a low clutter attenuation filter, or no filtering, to the data. The primary driving force behind this decision is to limit the possibility of underestimating precipitation due to the attenuation caused by the wider filters.

What has been observed operationally is that the NEXRAD operators will utilize the NEXRAD clutter filters to attenuate ground clutter that is present under normal propagation conditions. However, when the ground clutter changes dynamically (e.g., when an inversion is created by cold thunderstorm outflows), the clutter filter usage is not changed dynamically even though the operators recognize that a substantive fraction of the reflectivity products are corrupted by ground clutter.

The NEXRAD layered reflectivity products will be used by enroute controllers via the Weather and Radar Processor (WARP) and terminal supervisors and traffic management units via the Integrated Terminal Weather System (ITWS) to direct and plan traffic. These air traffic users do not have the data (e.g., NEXRAD 3D velocity products) nor training to recognize false returns. Hence, it is essential these products be free of false echoes. ITWS also uses the data to help eliminate or reduce the intensity of AP returns in the Airport Surveillance Radar (ASR–9) weather channel data. If the NEXRAD and ASR–9 AP returns are co–located, this can cause serious contamination of the ITWS precipitation product. In order to mitigate this, MIT Lincoln Laboratory (MIT/LL) has developed and tested an algorithm that removes AP from the NEXRAD reflectivity data.

In this paper, we will first provide a brief description of the algorithm. Next, we will present the truthing methodology used to identify AP. Then, we will show the algorithm performance results and failure mechanisms with this initial version. Finally, we consider refinements to improve the algorithm's performance.

2. ALGORITHM DESCRIPTION

This algorithm is designed to remove ground clutter contamination in the NEXRAD composite reflectivity maps. The distinguishing characteristics of the ground clutter to be identified by the algorithm are (1) low radial velocity, (2) narrow spectrum width, and (3) most commonly is found in scans near the ground. Based on the altitude and down–range distance of the sampling volume corresponding to a given data bin, as well as the radial velocity and spectrum width of the return signal, the data bin is classified as representing either "weather" or "clutter". Those data bins classified as containing clutter can be ignored during the subsequent generation of NEXRAD precipitation products.

The algorithm initially attempts to identify AP in the NEXRAD base data by three different techniques. First, any data bin that contains a reflectivity >/= 10 dBz, a velocity <1 m/s, and a spectrum width <1 m/s is classified as an AP CELL. Second, the algorithm searches 8 bins forward and backward from an AP CELL and classifies the bin as AP BLOOM if the velocity is less than 1 m/s. This approach is less restrictive since those bins in close proximity to an AP CELL are most likely AP. Third, in those regions with no velocity/spectrum width data such as at the Unambiguous Range Limit (URL), the algorithm attempts to extend the AP flagging based on reflectivity continuity. This technique is employed whenever one–quarter of the 16 km prior to the URL are flagged as either AP CELL or AP BLOOM and continues until more than one–quarter of the last 12 km contains bins flagged as weather.

In order to edit AP from the composite reflectivity maps requires that a given data bin is first located with respect to defined regions of space relative to the radar as shown in Figure 1. In this figure, there are three distinct editing regions, e.g., OMIT_ALL, ACCEPT_IF and REJECT_IF.

All reflectivity data in the first region (OMIT_ALL) are declared clutter. This region is bounded by an altitude of 1 km AGL and a down–range distance of 45 km.[1] Reflectivity data in the second region (ACCEPT_IF) are considered clutter unless indicated otherwise by either a high radial velocity or a wide spectrum width. This region is bounded by a distance between 45 and 103 km and is applied to all bins whose nominal elevation is less than or equal to 0.5 degrees (Figure 1). The altitude requirement for this region varies from 1 km AGL at the near range to 3 km AGL at the far range. In the final region (REJECT_IF), reflectivity data are considered as being free of clutter unless indicated otherwise by a low radial velocity and a narrow spectrum width. Any data bin whose nominal elevation is less than 5.0 degrees and down range distance is less than 230 km and is not in either region OMIT_ALL or ACCEPT_IF, is considered to be in this

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1. This use of an altitude "floor" at close range is similar in spirit to the NEXRAD Precipitation Processing Subsystem (PPS) which rejects the lowest tilt of data if the areal coverage of the next highest tilt is reduced by an amount greater than that expected for meteorological targets, e.g., 75 percent (Hunter, 1996). The main disadvantage of the PPS approach is it will remove shallow weather echoes that are only detected on the lowest tilt.

region. For a more detailed description of this algorithm, refer to MIT/LL (1995).

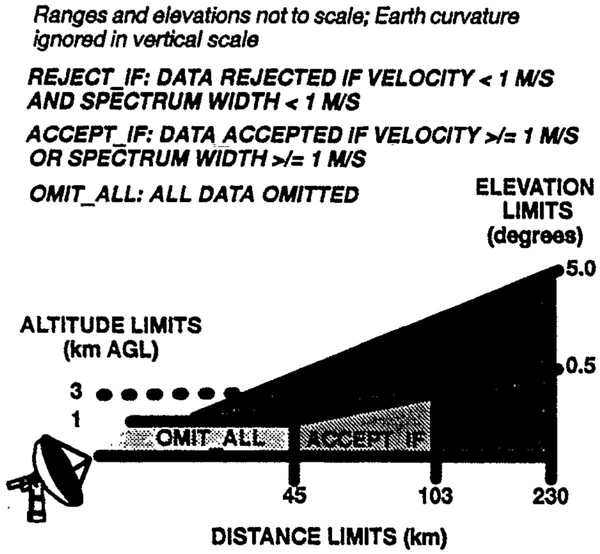

Figure 1. Region boundaries and names used by the MIT/LL NEXRAD clutter removal algorithm.

3. TRUTHING/SCORING METHODOLOGY

For this analysis, we selected ten cases from Memphis (MEM) that either exhibited AP only, weather only, or a combination of both. In order to identify regions contaminated by AP required an examination of the reflectivity and velocity data for all elevation angles in the volume scan. Data from the aloft angles were used to discriminate AP from weather based on the vertical reflectivity structure. Each patch of contiguous AP was enclosed by a polygon with a reflectivity threshold to distinguish the AP from the clear–air returns. The clear–air threshold was defined as the upper limit of the clear–air returns within the polygon. For some of the events, there were weather echoes intermingled with the AP. In this case, a second polygon was used to identify those bins within the AP polygon that contained weather.

4. PERFORMANCE RESULTS

The performance results are shown in Table 1. Overall, the algorithm removed 67.6 percent of the AP bins and 4.1 percent of the weather bins from this data set. If we analyze the algorithm performance on a case–by–case basis, there was significant variability from the average. The most significant case of overediting was on 950630. This was a case with small, isolated echoes that showed little or no cell motion. Thus, there were large patches of near–zero velocities associated with the weather echoes.

TABLE 1. Algorithm Performance Results

DATE	Prob. of Editing Anomalous Propagation (PEAP) (percent)	Prob. of Existing Weather (PEW) (percent)
940701	67.5	1.9
950630	–	9.2
950707	84.7	3.5
950711	62.5	–
960420	72.7	0.4
960421	55.7	1.0
960507	31.2	0.3
960507	–	1.2
960525	83.8	2.5
960612	79.6	2.3
OVERALL	67.6	4.1

5. FAILURE MECHANISMS

We have identified three major limitations of this algorithm:

1. Does not perform well in regions with no velocity/spectrum width data,
2. Does not perform well if the AP is intermingled with high reflectivity clear–air returns, and
3. Does not perform well if the AP region contains range folded weather echoes or noise.

In order to further define the limitations, the flags were modified to include four major failure mechanisms based on the algorithm thresholds, lack of data, and range folding. The results of this analysis are shown in Table 2. The primary cause for incorrect AP flagging was contamination from range folded weather echoes. More than one–half of the failure cases were caused by this problem. The vast majority of the remaining failure cases were due to the velocity or spectrum width thresholds being exceeded. Only five percent of the AP flagging failures were caused by a lack of velocity/spectrum width data. These results suggest that the greatest performance improvement could be achieved by adjusting the algorithm to better account for range folded weather bins intermingled with AP bins.

TABLE 2. Frequency of Failure Mechanisms

Reason for Incorrect AP Flagging	Frequency (percent)
Range Folding	58.0
Velocity Above Threshold	20.8
Spectrum Width Above Threshold	15.9
No Velocity/Spectrum Width Data	5.3

6. ALGORITHM MODIFICATIONS

Based on this analysis, we propose several modifications to improve the algorithm's performance. The first would be to perform a reflectivity texture analysis such as median filtering on the edited data. It is critical that this procedure be implemented on the higher resolution base data to ensure the filter does not remove small storms from the composite maps. The second change would be to adjust the velocity/spectrum width thresholds up slightly to determine the PEAP versus PEW trade–off. We are currently evaluating whether parameter modifications can provide a significant increase in the editing of AP without adversely impacting the editing of weather echoes.

Figures 2A and 2B are examples of an unedited and AP edited composite map for the 940701 event. The majority of the echoes between 190 and 020 degrees are weather, while the majority of the echoes between 020 and 190 degrees are AP. The algorithm only does a marginal job of eliminating the AP contamination for this event. There are large patches of unedited AP that correspond to the velocity range limit, e.g., 150 to 180 km. The algorithm performance was degraded by missing data, range folded data, and stratiform weather echoes intermingled with the AP. The majority of the AP residue for this and most other cases is "speckled" in nature and is easily distinguishable from the weather. It could be removed by a two–dimensional median filter which requires the majority of the bins within the filter contain valid data. If the majority of the data bins within the filter are flagged as bad due to AP, the remaining unflagged AP bins will also be set to bad. Since the weather returns are contiguous, the filter would have little negative effect except for the low reflectivity returns at the edge of the echo.

7. CONCLUSIONS

An algorithm designed to remove AP contamination from the NEXRAD data was developed and tested using ten events from MEM. This algorithm has the dual advantage of removing AP contamination, with only a slight impact on the removal of valid weather echoes. Specifically, it removed 67.6 percent of the AP bins and only 4.1 percent of the weather. The performance could be improved even further by implementing a median filter on the base data to remove the AP "speckle" that remains after the initial editing phase. We strongly recommend this technique be included in the final algorithm configuration.

Further improvements might be achieved by implementing techniques found useful in other systems. In addition to clutter filters, the ASR–9 Wind Shear Processor system identifies echoes with spectral characteristics indicative of ground clutter by a technique which determines the difference in signal return between the all–pass and the least attenuating filter (Cullen, 1996). If the difference exceeds a pre–defined threshold, e.g., 29 dB and the data bin is not flagged as containing ground clutter by the clutter maps, it is considered to be AP (Cullen, 1996). This approach has the advantage of removing AP with the least attenuating filter, while maintaining the integrity of the weather returns when they exceed the residue clutter.

8. ACKNOWLEDGMENTS

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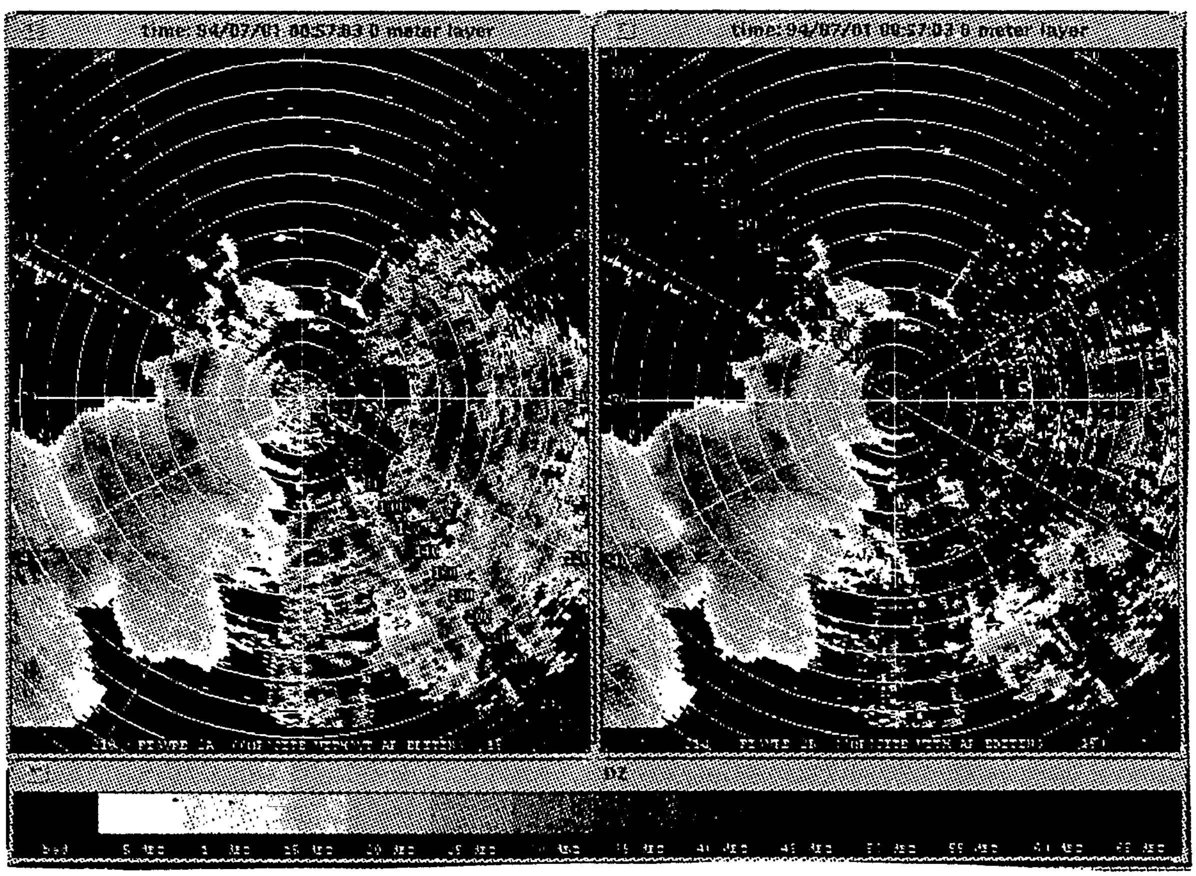

Figure 2. Composite reflectivity map without AP editing (2A, left) and with AP editing (2B, right). Range rings are in km.