7B.7 NON-WEATHER ECHO IDENTIFICATION FOR CONVENTIONAL OPERATIONAL RADAR

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1. INTRODUCTION

The removal of non-weather echoes is a fundamental priority for reliable quantitative estimates of rainfall from radar measurements for hydrology. Non-weather echoes are often variable in time and location, resulting in the need for highly adaptive identification procedures. Dynamic identification procedures have the additional benefit of allowing precipitation measurements to be retained when they dominate in regions of pre-existing clutter.

Recently developed procedures for the identification and elimination of non-weather echoes are applied to two distinctly different conventional weather radar systems within the existing framework of clutter removal for the respective systems. In one case, the procedure is applied in Cartesian co-ordinates to an operational S-band radar system operated by Météo France. In the other case, a similar procedure is applied to operational C-band radar systems operated by the UK Met Office in polar co-ordinates.. These procedures utilize a measure of the inter-pulse variability in terms of reflectivity, *Sigma,* and a measure of horizontal reflectivity gradients, *MxGradH*. The ability of the methods described is statistically evaluated on large data sets in non-precipitating conditions. Equivalently, the occurrence of false detection is evaluated in a similar manner for precipitation. Examples of the more difficult conditions encountered are presented. These include anomalous propagation, snowfall and scattered showers.

This paper presents new methodologies, which increase clutter removal efficiency for conventional radar, and provides robust statistics on the influence on precipitation. The two criteria used in the clutter removal algorithms are introduced in section 2. In the subsequent two sections, the methodology which has been incorporated within two pre-existing clutter removal procedures, which previously utilized *Sigma* alone, are described along with the evaluation procedures and results.

2. IDENTIFICATION CRITERIA

2.1 *Sigma*

A measure of the inter-pulse variability (the mean absolute difference in dBZ) has been shown to be a useful tool for dynamically identifying regions affected by ground clutter (e.g. Ayoagi, 1983, Wessels and Beekhuis, 1994).

Sigma is defined in the following equation:

$$Sigma = \frac{1}{M-1}\sum_{k=1}^{M}\left|dBZ_k - dBZ_{k-\tau}\right| \qquad (1)$$

where dBZ_k is the radar reflectivity at a particular range gate for a transmitted pulse *k*, $dBZ_{k-\tau}$ is the radar reflectivity for a transmitted pulse $k-\tau$ and *M* is the number of pulses averaged.

Typical values of this criteria are centred above 5 dBZ for precipitation and typically much lower for ground clutter. Recent work (Sugier et al, 2002, Nicol et al, 2003a) has highlighted the primary considerations and limitations of this approach. The two important considerations in this calculation are: firstly, sufficient time between the pulses used to calculate the absolute difference (in order to obtain independence in precipitation and hence sufficiently large values of *Sigma*), and secondly, sufficient averaging to reduce the spread of estimates based on statistical uncertainty. A by-product of the combination of sufficient inter-pulse spacing and the scan rates required for volume scans is the influence of exaggerated clutter gradients, which lead to enhanced *Sigma* values around the edges of ground clutter and impede their identification.

2.2 *MxGradH*

It has been shown (Nicol et al. 2003b) that the maximum absolute isotropic gradient calculated relative to neighbouring pixels on a scan-by-scan basis is a useful accompaniment to *Sigma*. The removal of measurements with high gradients (e.g. *MxGradH* > 8dB/km) which are adjacent to *Sigma* identified clutter can increase the clutter removal efficiency to over 99%. This criteria is defined as follows:

$$GradH_{i,j} = \left|\overline{dBZ}_i - \overline{dBZ}_j\right| / d \qquad (2)$$

where for any grid point *i* (polar or Cartesian) the absolute difference is calculated for each of the eight horizontally adjacent grid points *j* which are then normalised to dB/km by dividing by *d,* the distance between the mid-points of the two grids. Finally, *MxGradH* is obtained by selecting the maximum.

3. APPLICATION TO METEO-FRANCE RADAR

The following procedure for ground clutter identification was applied to an S-band radar operated by Météo France as part of the ARAMIS network. The radar is located at Bollène, south-eastern France, a region subject to intense rainfall and severe ground

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clutter due to its location between two mountain ranges. The radar was operated over a 4-month period in a trial volume-scanning protocol. This protocol required faster scan rates than had been previously used (10°/s and 15°/s, or 1.66 and 2.5rpm, respectively) which proved detrimental to the previous clutter removal procedure based on *Sigma*.

Reflectivity and *Sigma* measurements are averaged into a 1km x 1km Cartesian grid, resulting in an average of around 120 measurements at 50km for the 10°/s scan rate or around 80 measurements at 15°/s, this number decreases linearly with range. The *Sigma* values are calculated between each second pulse, equivalent to a temporal separation of 8ms.

In this case, the intention is to test the sensitivity of a combined *Sigma*/*MxGradH* filter to the respective thresholds selected. The *Sigma* threshold was given values between 0.5 and 5dBZ in 0.5dBZ steps and the *MxGradH* threshold was allowed to vary between 3 and 10dBZ/km in 0.5dBZ/km steps. Two parameters were computed to evaluate the performance of the new clutter identification algorithm. Firstly, the false-detection probability (FDP) represents the percentage of precipitation wrongly classified as ground clutter. Conversely, the second, the true-detection probability (TDP) represents the percentage of clutter pixels successfully identified by the algorithm. For each pair of thresholds, the corresponding FDP and TDP were calculated.

The FDP was calculated as follows: a statistical clutter map was obtained from 12 dry days chosen within the 4-month period. In order not to take clear air echoes into account, which typically occur at night within 30km of the radar, only measurements made between 8 and 18 UTC were used. On the basis of the resulting average clutter map, only pixels equal to or less than 0dBZ were considered clutter-free. Then, 36 images taken from 6 rainy days were considered and 358 528 pixels were tested. The analysis was restricted to within 100 km of the radar, to pixels with reflectivity above 8dBZ (the first range class represents measurements between 0 – 8dBZ) and to pixels falling within the previously defined "clutter-free" area. To compute the TDP, 42 images taken from 6 dry days were used yielding a total of 428 222 pixels. In this case, the algorithm was applied to all pixels having a reflectivity above 8dBZ. The algorithm may be summarised as follows. Firstly, if a pixel has a value of *Sigma* below the *Sigma* threshold then it is marked as clutter. Then for each non-clutter pixel adjacent to a clutter pixel, *MxGradH* is calculated. For each of these pixels, if the value of *MxGradH* is above the *MxGradH* threshold, it also is marked as clutter.

Examples of the results for the 0.8° elevation scan at 10°/s are presented in Figure 1. It shows that to obtain a minimum TDP of 98.5% for clutter intensity greater than 8 dBZ, *Sigma* threshold should set to 3dB and a *MxGradH* threshold set to 6.0dB/km. This satisfies the clutter removal efficiency and gives an FDP of 2.42%. Furthermore, TDP increases to 99.84% and FDP reduces to 2.12% for echoes above 20dBZ. At the faster scan rate (15°/s) for an elevation angle of 0.4° with the same clutter removal efficiency (TDP of 98.5% above 8dBZ), FDP raises to 5.55%, whilst using the optimum combination of *Sigma a*nd *MxGradH* thresholds (3.5dBZ and 9.5dBZ/km respectively). However, for echoes greater than 20dBZ, TDP increases to 99.82% and the FDP reduces to 4.64%.

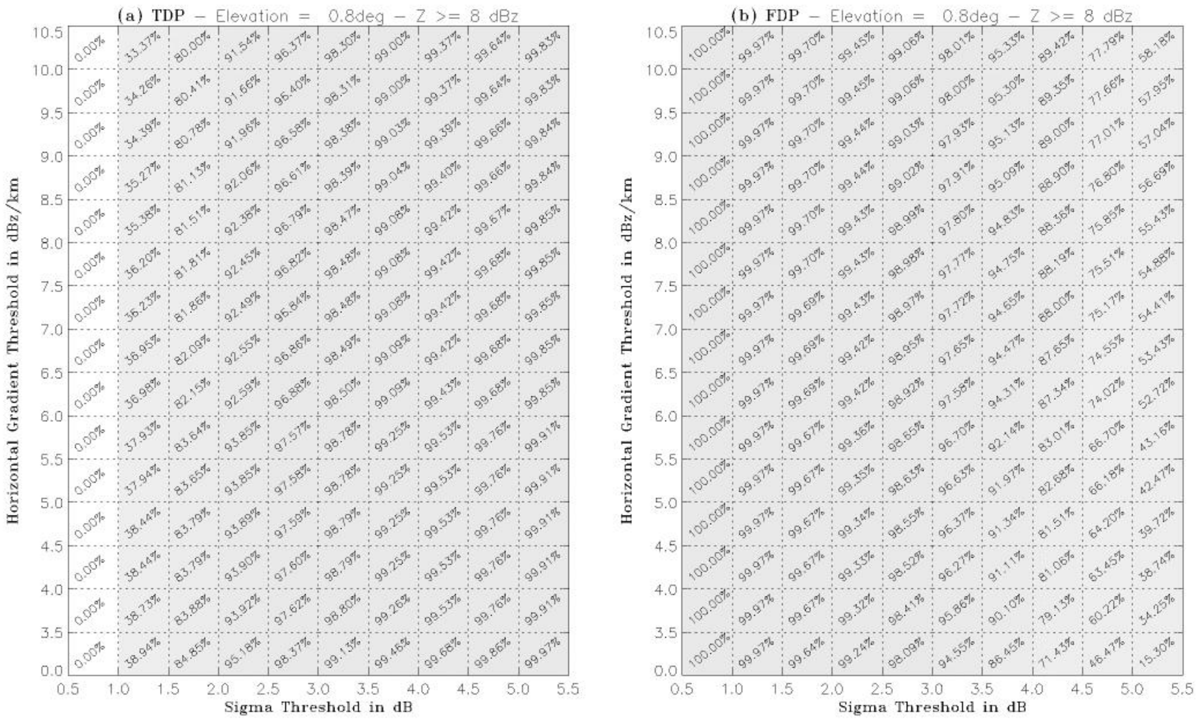

Figure 1: FDP and TDP percentages calculated as a function of *Sigma* and *MxGradH* thresholds

4. APPLICATION TO MET OFFICE RADAR

4.1 Implementation

The UK Met Office operates a network of C-band radar. Reflectivity and *Sigma* measurements are averaged over a 1.0° x 750m polar grid, which ensures an average of 100 measurements. The radar scan rate is 7.2°/s (1.2rpm) and *Sigma* values are again calculated using the difference between each second pulse, equivalent to a temporal separation of 6.6ms. For each radar, the UK Met Office produces clutter maps every month based on the accumulative detection count of echoes above the noise threshold (around –3dBZ at close range and 1dBZ at 255km) over the previous three months. The map is expressed as a frequency of detection (FOD) for each of the polar pixels. This clutter removal algorithm applies different *Sigma* thresholds depending on the FOD. The thresholds are 3.5dB for areas with FOD > 20% (areas likely to be clutter) and a lesser threshold of 2.0dB for the remaining regions which are typically free of clutter. Hence, measurements with *Sigma* below these thresholds are marked as clutter and *MxGradH* is calculated for all adjacent non-clutter measurements. For measurements with FOD > 20%, the *MxGradH* threshold is 8dB/km, otherwise it is set at 12dB/km, and measurements with *MxGradH* above the thresholds are also marked as clutter. As a final step, for remaining measurements with FOD > 20%, the measurements are marked as clutter if 5 or more of the adjacent measurements have previously been marked as clutter. For measurements in other regions, they are marked as clutter only if fully surrounded by identified clutter. This final stage removes isolated returns such as those from planes.

FDP and TDP were again calculated, though in a somewhat different manner. FDP is evaluated by observing the effect of the procedure on pixels with low FOD (i.e. less than 15%) during precipitation; and TDP focuses only on pixels with high FOD (i.e. greater than 80%) in non-precipitating conditions. TDP and FDP are evaluated using data sets comprised of various events collected between April 2002 and March 2003. The results for seven different radar systems are shown in Table 1. The precipitation data set is comprised of events with various types of precipitation from homogeneous slow-moving frontal rain to fast-moving scattered showers and hailstorms. Snow events were not included but are studied separately later. Results of the percentage of rain removed (FDP) range from 0.85% to 3.25%. Echoes other than precipitation may be present in areas of low FOD e.g. echoes from planes, interference from other microwave sources and anaprop occurring in close proximity of storms. These echoes may be removed by the analysis leading to an overestimation of FDP by an unknown and unpredictable amount. To illustrate the effect of the presence of interference and/or AP near the precipitation areas, the data set collated for Ingham was reviewed and dubious scans removed from the analysis. This resulted in a reduction of FDP from 3.25% to 1.06% (based on 602 scans). Overall, the study of the two data sets is very encouraging, with on average more than 99% of fixed clutter removed (TDP) and only 2% of rain (FDP).

Radar site name	**Wet data set FDP (%) and number of scans**		**Dry data set TDP (%) and number of scans**	
Hameldon Hill	2.51	1294	99.97	267
Chenies	1.55	1480	99.97	842
Castor Bay	2.24	1480	99.85	843
Ingham	3.25	1325	99.91	490
Crug-Y-Gorrllwyn	1.03	1122	100.0	297
Wardon Hill	0.85	1025	99.99	440
Druima Starraig	2.50	1513	98.50	597
	FDP = 2.0 % ± 0.8 % over a total of 31 days		**TDP = 99.7 % ± 0.5 %** over a total of 13 days	

Table 1: Percentage of rain removed (FDP) and clutter removed (TDP) using a collation of scans with and without precipitation, respectively.

Radar site name	**Date**	**Event characteristics**	**Wet data set FDP (%) and number of scans**	
Chenies	08 Jan 2003	Slow falling snow flakes	1.86	135

Table 2: Percentage of rain removed (FDP) during a snowfall event

Radar site name	**Dates**	**Event characteristics**	**Wet data set FDP (%) and number of scans**	
Chenies	03 Nov 2002 10:00-19:00 UTC	Fast moving showers and hailstorms	1.61	98
Castor Bay	05 Mar 2003 10:00-19:00 UTC	Slow moving light scattered showers	2.23	120
Ingham	07 Aug 2002 17:00-19:00 UTC	Fast moving scattered storms	1.79	23
Crug-Y-Gorllwyn	03 Mar 2003 20:00-24:00 UTC	Slow moving light scattered showers	2.15	44
Druima Starraig	05 Mar 2003 10:00-19:00 UTC	Slow-moving light scattered showers	2.18	120

Table 3: Percentage of rain removed (FDP) using a selection of scattered shower events.

4.2 Snow event case study

The first stage of the UK Met Office clutter elimination scheme bypasses the *Sigma* < 2dB test on all data if the probability of snow is greater than 50%. This was done because previous studies concluded that the performance of the *Sigma* scheme deteriorates when sampling slowly falling snowflakes. However, for a snow event (Table 2), the percentage of precipitation removed remains within tolerance, i.e. < 2%.

4.3 Scattered shower case studies

Although scattered showers are included in the main data set, it is interesting to focus on these events because the horizontal gradients are likely to be higher in precipitation areas and might lead to an increase in the amount of rain misdiagnosed as clutter. Table 3 shows the FDP obtained during scattered showers at five sites. The percentage of rain removed ranges from 1.61 % to 2.22 % and does not significantly differ from the results obtained with the analysis of the large data set.

4.4 Anomalous Propagation case studies

The efficiency of the scheme in removing anaprop is more difficult because no guarantees can be given about the true nature of the returns. In the present study, cases were selected using expert judgement that atmospheric conditions for sub-refraction exist and also using a probability of precipitation, based on the analysis of satellite images and mesoscale model output. For the study of anaprop events in dry conditions, TDP represents the percentage of non-fixed returns successfully removed by the procedure. Non-fixed returns are selected if they occur in pixels with FOD < 80%. Note that scans contaminated by interference from other microwave sources are not removed from the data sets. These could introduce an underestimation of TDP by around 2% for sites such as Chenies, which are prone to significant interference. Table 4 shows that around 75% of anaprop are successfully removed by the new scheme. Furthermore, the inclusion of the gradient criteria leads to an increase of anaprop removed of up to 25%.

Radar site name	**Wet data set** **TDP(%) and number of scans** **A**	**B**	
Hameldon Hill	70.93	55.42	1119
Chenies	73.94	51.06	364
Ingham	76.78	51.90	708
Crug-Y-Gorllwyn	78.46	65.28	741
	A: TDP=75.0 % ± 3.5 % **B: TDP=55.9 % ± 6.5 %** over a total of 10 days		

Table 4: TDP using a selection of dry weather anaprop events. A- using both criteria, and B- using only Sigma.

5. CONCLUSIONS

Despite the different approaches and radar systems used in this evaluation, very similar results were obtained. For the analysis of the Météo France data, the TDP was evaluated over the entire domain not just regions of high FOD. This includes the ability to identify transient clutter and perhaps for this reason, slightly higher values of FDP were observed for equivalent values of TDP. Because the time to independence in precipitation is proportional to wavelength, the S-band system would again be expected to provide higher values of FDP, due to underestimates of *Sigma* in precipitation. Further improvements may be achieved using a larger pulse separation to calculate *Sigma.*

A new scheme was applied to UK Met Office radars with the intention of improving the clutter removal efficiency with the inclusion of a new parameter based on the horizontal reflectivity gradient. This was tested on seven sites over the UK radar network using a wide range of meteorological conditions. At five of the seven sites considered, the new scheme was found to remove over 99.9% of fixed ground clutter. The term 'fixed' is used to indicate that these values were only evaluated in regions where returns were present at least 80% of the time in the previous three months. The previous scheme had been found to remove between 90% and 98% of fixed ground clutter with less than 2% of rain misdiagnosed. Hence, a significant improvement has been obtained with no significant reduction of precipitation measurements. The scheme was also able to identify 75% of anomalous propagation. Without, the inclusion of the gradient criteria only 50% was detected.

The new methodologies seem efficient for the dynamic identification of ground clutter and highlight the trade-off between identification efficiency and the effect on precipitation. For operational applications, the decision must be made as to whether the priority is given to a minimum of residual clutter (e.g. TDP > 98.5%) or to a minimal influence on precipitation (e.g. FDP < 2%). This choice, naturally depends on the scanning protocol employed and the demands of end-users.

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