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TWDR Clutter Residue Map Generation and Usage

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16. Abstract

The Terminal Doppler Weather Radar (TDWR) system is designed to provide high quality low altitude Doppler radar data near airports. Ground clutter suppression will be a major challenge to supplying such high quality Doppler data. To confront this challenge the FAA has specified stringent clutter suppression requirements in the TDWR technical specifications.

These specifications are designed to provide an effective clutter suppression system. In particular, the specifications require an antenna with narrow beam width and low side-lobes to minimize ground target illumination. Also, a high pass frequency filter (with a stop attenuation in excess of 50 dB) is required to reduce stationary clutter. Finally, a clutter residue map editing system is used to remove remaining clutter.

This report describes the algorithms used to generate and use the clutter residue editing system. The major issues are discussed followed by a description of the algorithms designed to address these issues. Finally, preliminary experimental results using a clutter residue map are presented.

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ACRONYMS

C–band	Radar frequency of TDWR with a wave length near 5 cm
CPI	Coherent Processing Interval
FL–2	FAA/Lincoln Laboratory weather radar testbed
ICV	Inter–Clutter Visibility
NEXRAD	NEXt generation weather RADar
PPI	Plan Position Indicator, a circular display of radar data in a range versus azimuth format
S–band	Radar frequency of NEXRAD with a wave length near 10 cm
SNR	Signal to noise ratio
TDWR	Terminal Doppler Weather Radar
X–band	Radar frequency with a wave length near 3 cm
σ_0	measure of area reflectivity with units of m^2/m^2

1. Introduction

This report discusses the clutter residue map editing system which removes ground clutter where the antenna beam width and high pass filters have not adequately suppressed it. A clutter residue system is called for in the TDWR (Terminal Doppler Weather Radar) specification [FAA, 1987]. The algorithms necessary to generate and utilize a clutter residue map are described along with results from a prototype system.

1.1 Background

The requirement for a clutter residue editing system stems from a consideration of the clutter suppression necessary to achieve the design goal of detecting low altitude wind shears. Dangerous wind shears are often associated with a low reflectivity outflow region, occasionally as low as 0 dBz. Outflows with such low reflectivities represent an important detection challenge both from the viewpoint of system sensitivity and elimination of ground clutter.

Ground clutter measurements near major airports have been made by Lincoln Laboratory using the FAA transportable Doppler Weather Radar and a X-band clutter measurement system. Figures 1-1 thru 1-3 display low elevation scans at airports near Dallas, TX, Huntsville, AL, and Denver, CO, respectively. The results from these measurements [Mann, 1986] as well as the literature [Nathanson, 1969][Skolnik, 1980] demonstrate that ground clutter can have a median reflectivity as high as -40 dBσ_0 (corresponding to a reflectivity of 46 dBz at 10 km for C-band). Clutter from discrete scatterers such as buildings can have clutter cross sections of 1 m^2 to 30 m^2 (corresponding to a reflectivity of 41 dBz to 55 dBz at a range of 10 km for C-band). Figure 1-4 shows the clutter scattering cross section as an equivalent weather reflectivity over operational ranges.

The clutter suppression needed to accurately measure the velocity (i.e. with a bias of less than 1 m/s) of a signal with a reflectivity of 0 dBz can be illustrated in figure 1-4. To obtain this velocity accuracy a signal to interference ratio of 10 dB [Doviak and Zrnic 1984] is necessary. For an off airport site, 10 kilometers from the airport, a clutter cross section of -40 dB would be reported with an equivalent reflectivity over 46 dBz. Thus, an overall clutter suppression of 56 dB is needed.

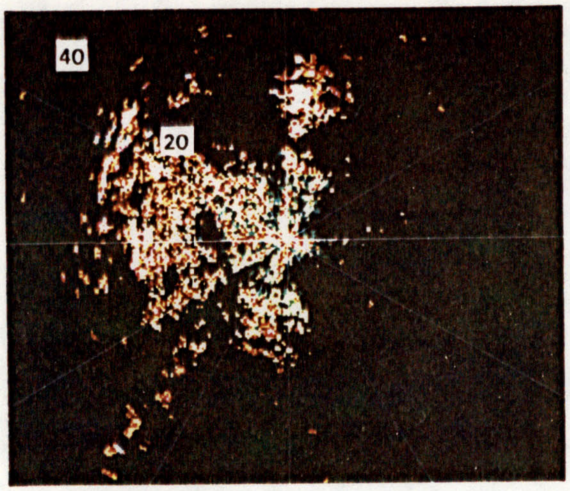


Figure 1-1. Clutter data collected with X-band clutter measurement system near Dallas, TX.

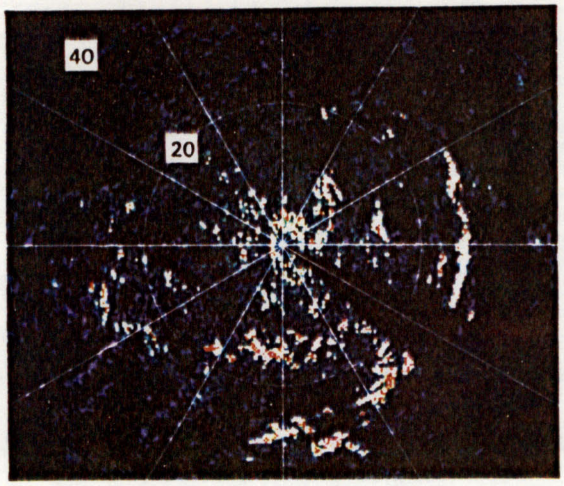


Figure 1-2. Clutter data collected with FL-2 near Huntsville, AL.

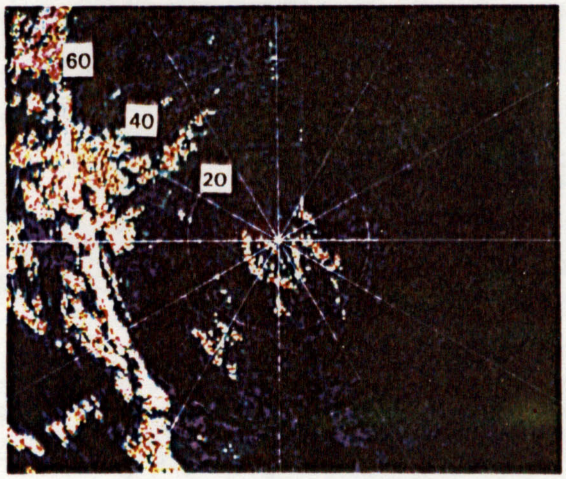
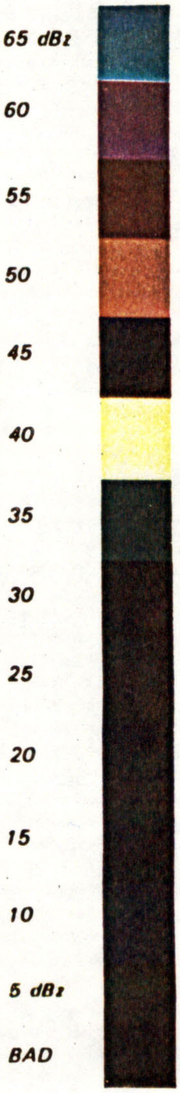


Figure 1-3. Clutter data collected with FL-2 near Denver, CO.



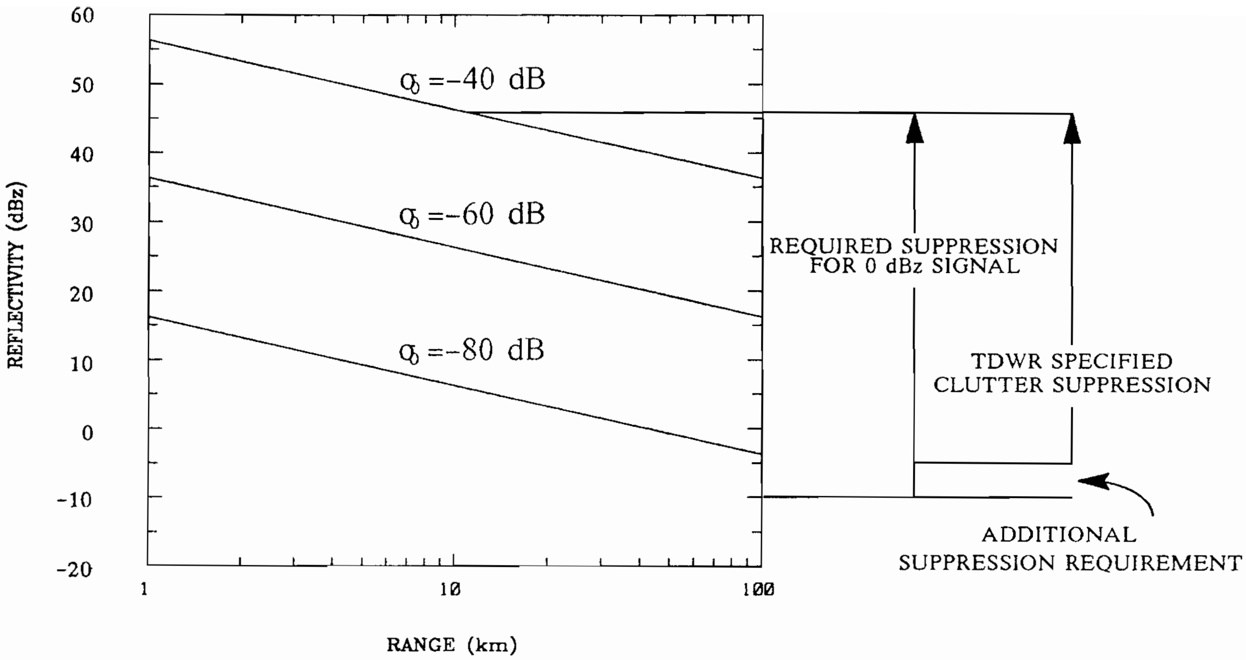


Figure 1-4. Equivalent reflectivity of clutter cross section (at C-band) as a function of range.

The TDWR system utilizes clutter mitigation techniques that are similar to the NEXRAD system [EVANS, 1983] [NEXRAD JSPO, 1986] with the addition of a clutter residue map editor. The clutter environment associated with a TDWR is more challenging than that of a NEXRAD due to the low elevation scanning areas and the low reflectivity wind shear targets. The low altitude location of wind shear outflows makes main beam illumination of ground clutter unavoidable. The following methods of clutter suppression are called for in the TDWR specification:

a) a narrow antenna beam pattern,

b) high pass clutter filters, and

c) a clutter residue map editor.

The siting guidelines for TDWR suggest the use of sites which minimize clutter illumination in the vicinity of the airport. Further reduction of clutter illumination is achieved by the narrow pencil beam antenna pattern. However, the optimal radar location is not always available due to land acquisition constraints. The high pass clutter filters are an effective and reliable method for reducing clutter returns. This method alone is not sufficient, however. The attenuation resulting from the high pass clutter filters in the specifications is not great enough to suppress the level of clutter cross section below possible dry microburst and gust front outflow reflectivities. Additionally, clutter from moving objects such as vehicles on a highway may not be suppressed at all by the high pass filters. A clutter residue map editor is an effective method for eliminating both residual stationary clutter and moving spatially stationary clutter such as vehicular traffic.

1.2 Clutter Residue Map Overview

A clutter residue editing system uses a polar map of residual clutter magnitudes as a threshold for weather measurements. A map of post-filtered clutter is recorded on a "clear day" and is used to set up a threshold for weather data independently for each range-azimuth cell. During operational weather detection, range-azimuth samples are compared to the corresponding clutter residue map values. If the measured levels are less than the map levels, the data is flagged as invalid.

A clutter residue map editor does not reduce the actual clutter measurements, rather it reduces the apparent local area clutter. This type of system exploits the spatial inhomogeneities in the residual clutter and uses "inter-clutter visibility" (ICV) to resolve and eliminate range-azimuth cells with large residue levels.

A principal objective in using a clutter residue map is to reduce the number of false wind shear alarms reported by automated detection algorithms which are caused by clutter contamination. An apparent wind shear can be caused by a region of zero velocities due to clutter in an otherwise uniform wind field since an abrupt change in measured radial velocity may be interpreted as a wind shear. By flagging the data from the clutter cell, the anomalous velocity measurement is ignored by the wind shear detection algorithms and the apparent shear is eliminated. The clutter residue editor may also improve the detection probability of a wind shear by removing anomalous velocity spikes in the radial velocity field (e.g. caused by moving targets such as cars) that could confuse the radial shear feature extraction algorithm.

This report discusses the implementation of an automated clutter residue map data editing system. Chapter 2 discusses the major issues involved with implementing and operating such a system. In chapter 3 the algorithms for generating and using clutter residue maps are specified. Experimental results using an initial implementation of a clutter residue map editor are presented in chapter 4. The paper is concluded with a discussion of enhancements and proposed future work.

2. Algorithmic Issues

A clutter residue map editing system can be divided into two algorithms, map utilization and generation. The utilization algorithm applies a finished map as a spatial threshold to measured weather data. The generation algorithm is used to construct and modify the clutter residue maps. This function is perhaps the more important of the two, for a residue map which accurately represents the clutter is the keystone to a working system. This section discusses the issues involved in implementing a working clutter residue map editing system.

2.1 Map Utilization Issues

The operational function of a clutter residue editing map is to serve as a spatial threshold for weather measurements. As specified in section 3.3, each operational weather measurement is spatially associated with a clutter residue map cell. The corresponding map value is used as a threshold below which the weather level is considered invalid.

Clutter returns from trees and crops are well known to be random processes. Due to the statistical nature of these clutter sources, it is possible for an instantaneous clutter level to be greater than its corresponding map value. With this case, the measured value will be interpreted as a valid weather measurement (even in the absence of weather). This occurrence is defined as clutter break-through.

Clutter break-through is the main issue pertaining to the clutter residue map utilization algorithm. The rate of break-through is dependent on the short term statistical behavior of the residual clutter. In fact, the rate may change with the weather environment (e.g. the wind speed). The regulation of the clutter break-through rate is handled in the utilization algorithm by the site adaptation parameter, X_{cr}, (as discussed in section 3.3).

In particular, the weather level must be X_{cr} times greater in magnitude than its corresponding clutter map cell level for the data to be considered valid. This multiplicative factor increases the representation of each map cell from a mean value to a higher quantile probability. The net effect is to reduce the chance of clutter residue break-through. While this method is effective for controlling the break-through due to short term variability, longer term changes in the clutter environment must be compensated for with the map generation algorithm.

2.2 Map Generation Issues

The longer term variability of clutter residue maps is typically caused by environmental changes that accompany seasonal changes or human activity (e.g. construction). These changes can be compensated for by constructing a new clutter residue map. The time interval between map generation is dependent on the sources of the local clutter. However, the residue maps must be updated on a regular basis to reflect the current state of the environment.

A clutter residue map is generated from measured data in two steps and can be manually modified in the final step. The first step is to determine the boundary layer reflectivity immediately prior to map generation. This reflectivity value, as well as site adaptable velocity and signal-to-noise (SNR) values are used to determine the valid clutter residue data. The next step is to time average and store residual clutter map values. The clutter residue map can then be modified by setting the values of desired map cells to a user supplied value.

The echoes from optically clear air become a problem when generating a clutter residue map because they mask the local residual clutter levels. The main source of these returns are variations in the refractive index (due to temperature and humidity variations), insects and dust.

All of these clutter sources act as tracers which can indicate the direction and velocity of the wind. Therefore, the resulting returns from these sources aid the wind shear detection algorithms. However, the inclusion of these measurement in a clutter residue map would result in increased map levels and the flagging of clear air measurements during weather detection. The benefit of these wind tracers would then be lost.

The underlying clutter residue levels rather than the clear air levels are the desired data for clutter map generation. The best solution to the masking problem is to generate a clutter residue map when there are no appreciable clear air returns. When this is not possible the clear air returns can be excluded with a reflectivity threshold. The algorithm specified in section 3.1.1 is used to compute the clear air reflectivity threshold for use during map generation. It should be suggested however, that map generation take place when the clear air returns are at a minimum.

Another issue concerning map generation is nonrepeatable clutter. Nonrepeatable clutter is considered to be any source of clutter which is not seen in the same range-azimuth location from scan to scan. Flocks of birds and planes are examples of nonrepeatable clutter. When included in a clutter residue map, nonrepeatable clutter will degrade the performance of the map utilization algorithm by needlessly flagging areas which infrequently have a significant clutter residue level.

The site adaptable parameter, N_{cr}, is used to minimize the obscuration of a clutter residue map by neutralizing clutter map cells which do not have a significant residue level often enough. Specifically, a map cell's values is set to zero if the number of recorded residue measurements in the corresponding range-azimuth cell is less than N_{cr}. This method of eliminating repeatable clutter residue is effective in removing these sources. However, some useful sources of semi-repeatable clutter such as automobiles may also be eliminated.

While vehicular clutter can be a significant source of false wind shear detections, these clutter sources may be inadequately represented in a residue map. A map that is generated during a low traffic volume period may have many of the range-azimuth cells zeroed by the N_{cr} threshold. Even a clutter residue map generated during a high traffic time may contain cells whose mean values are significantly lower than their median values due to the moving clutter sources. A possible side effect in either case is a large clutter break-through rate.

The manual modification algorithm specified in section 3.2 can be used to adapt each clutter residue map to any special local clutter phenomena including major roads near airports. In particular, a map cell is set to a site adaptable parameter if its location is within a user supplied polygon contour. The contours can be specified to outline roads or any other regular source of clutter break-through. Typically, the map levels are set to their highest value resulting in the deletion of the area enclosed in the polygon.

Many of these factors are significant challenges to constructing good clutter residue maps. The TDWR clutter residue map editor specifications are designed to meet these issues. The specifications of the algorithms are discussed in the next section.

3. TDWR Clutter Residue Editing Map Generation and Utilization Algorithm Specification

3.1 Clutter Residue Map Generation Using Measured Data

The clutter residue map generation is accomplished in two steps:

1) the antenna is scanned in the monitoring mode to determine the nominal surface boundary layer clear air reflectivity for the current time period.

2) the antenna is scanned repeatedly at the elevation angle for which the clutter residue map is to be updated to determine those clutter residual cells whose return exceeds that of the clear air.

Below we describe the antenna scanning pattern and signal processing used in each of these steps.

3.1.1 Clear Air Reflectivity Estimator

At the user specified clutter residue map update time, the TDWR shall determine a clear air reflectivity estimate, Z_{ca}, using the following algorithm:

a) The antenna shall scan in monitoring mode.

b) Reflectivity and velocity estimates shall be made between site adjustable range and altitude limits at the operational range sampling interval.

c) All reflectivity estimates with

   i) a signal-to-noise ratio (SNR) above a site adaptation threshold (SNR_{min}), and

   ii) a corresponding radial velocity whose magnitude exceeds an upper specified threshold (V_{ca})

   shall be used to form a clear air reflectivity histogram. This histogram shall have a resolution of 0.5 dBz, a lower limit of -20 dBz and an upper limit of +30 dBz.

4) The clear air estimate, Z_{ca}, is the lowest dBz value of the histogram for which there exists at least P_{ca} percent of the

histogram samples (i.e. Z_{ca}, is the P_{ca}^{th} quantile of the clear air reflectivity), provided that the total number of histogram samples exceeds the site adaptable parameter, N_{ca}. If the number of histogram samples does not exceed N_{ca}, a message to that effect shall be displayed to the user.

Typical values for the clear air reflectivity estimation site adaptation parameters are:

SNR_{min} = +6 dB,
V_{ca} = 3 m/s,
N_{ca} = 1000 and
P_{ca} = 50 %.

3.1.2 Clutter Residue Map Generation

During the time period where the clutter residue map for a site adaptable elevation angle is to be generated, the radar parameters shall closely approximate those used during the hazardous weather detection mode:

1) the antenna shall scan in a 360 degree continuous rotation at a site adaptable scan rate between 0.05 deg/sec and 30.0 deg/sec in a site adaptable direction,

2) the range sampling interval shall be identical to that used in operational weather detection, and,

3) the clutter filters utilized shall be identical to the clutter suppression level map used in operational weather detection.

The duration of scanning will be a site adaptation parameter (determined by the minimum acceptable number of samples per range-azimuth cell and the antenna timing).

The clutter residue map values are determined by time averaging all measured SNR values at each range-azimuth cell whose reflectivity exceed Z_{ca} and whose mean radial velocity suggests that the residue arises from a stationary source of clutter. Each measured SNR value shall be accepted only if the following conditions are met:

1) SNR is greater than SNR_{min},

2) the equivalent weather reflectivity is greater than $Z_{ca} + T_{ca}$, (where T_{ca} is a site adaptation parameter) and,

3) the corresponding radial velocity magnitude is less than V_{cr} (where V_{cr} is a site adaptation parameter).

Each valid signal-to-noise value, $P(r,\omega)$, is then associated with the clutter residue map cell $M(r,\theta)$ whose azimuth, θ, is closest to the measured angle, ω. The corresponding running sums are then updated:

$$S(r,\theta) = S(r,\theta) + P(r,\omega) \tag{1}$$

$$N(r,\theta) = N(r,\theta) + 1 \tag{2}$$

where,

$N(r,\theta)$ = number of data points to be averaged in the map cells at (r,θ)

When the clutter residue map scanning process is completed, the clutter residue map values are then set to the averaged measured level, i.e.,

$$M(r,\theta) = S(r,\theta) / N(r,\theta), \tag{3}$$

provided that $N(r,\theta)$ is greater than or equal to the site adaptable threshold N_{cr}. If $N(r,\theta)$ is less than N_{cr}, then $M(r,\theta)$ shall be set equal to zero.

Alternatively, the running sum using $S(r,\theta)$ can be replaced by a recursive form:

$$M(r,\theta) = \frac{1}{N(r,\theta)} P(r,\omega) + \left[\frac{N(r,\theta)-1}{N(r,\theta)}\right] M(r,\theta) \tag{4}$$

which directly yields $M(r,\theta)$ at the expense of more divide operations.

3.2 Clutter Residue Map Modification via Manual Entry of Filled Polygons

The intent of the manual clutter map modification function is to provide a mechanism to adapt each clutter map to any special local clutter phenomena which are not adequately included when using the automated procedure described above. The inclusion of a major highway is a typical example of the use of this function.

The Remote Monitoring Subsystem function of the TDWR shall provide the capability to set clutter residue map values for a specified clutter residue map to a user supplied value via user supplied polygons. The value shall be supplied in equivalent reflectivity units while each polygon shall be specified by up to 10 contour points. All clutter residue map cells whose centroid is within the contour of a polygon shall be set to the user supplied value for the corresponding polygon. The user supplied polygons and associated clutter residue values shall be stored in a file which can be edited, saved and used when the clutter residue map is next updated.

3.3 Clutter Residue Editing During Weather Detection Operational Modes

The measured weather levels (specifically, the SNR values) during the TDWR operational modes shall be compared with the corresponding clutter residue map levels. If the measured value does not exceed the effective clutter residue map threshold, the measured data is assumed to be clutter contaminated and is flagged as invalid.

Specifically, for a base product collected at (r, ω, ϕ) where the elevation angle ϕ is an elevation angle with a clutter residue map

a) determine the nearest residue map angle, θ, to ω

b) If the measured SNR at (r, ω, ϕ) is less than or equal to the product $X_{cr} * M(r,\theta)$, then flag the base product as invalid

where X_{cr} is a site adaptation parameter.

4. Results from an Initial Implementation of a Clutter Residue Editor

An off-line version of the clutter residue map editing system has been implemented at Lincoln Laboratory. Experimentation with this system has illustrated many of the issues previously discussed concerning an operational clutter residue map editing system. A summary of preliminary results is presented here.

The temporal variability of clutter residue values became a problem when we began experimenting with the concept of clutter residue map editing. Clutter returns from trees and crops are well known to be random processes. Realistically, the clutter map can only represent some statistical measure of the random process. A mean value estimator was chosen to represent the clutter residual values. This measure was chosen due to its mathematical usefulness and computation simplicity.

A clutter residue map of the area surrounding Stapleton Airport near Denver, Colorado, is displayed in figure 4-1. This residue map was generated using the batch averaging method detailed in section 3.1.2. Due to the calm winds during clutter data collection, the clear air reflectivity was visually estimated at 0 dBz rather than by the algorithm discussed in section 3.1.1.

The map was made to cover only the Western sector (180 to 360 degrees) to demonstrate the effect of clutter residue editing in the presence of clear air measurements. The discontinuity at the North-South line gives a visual indication of the impact of a clutter residue editor.

As with any random process, a particular time sample has a significant probability of being larger than the process' mean value. Any sample which is larger than its corresponding map value will pass through the system as a good value. The occurrence of a clutter residue value that has passed through the editor is considered a clutter break-through. Due to the statistical nature of the clutter sources, any data scan which is edited with a mean valued clutter residue map will contain a great deal of clutter break-throughs.

Figure 4-2 shows a scan containing clutter residue break-through. This image was the result of editing a PPI scan which does not contain any convective weather signatures with a mean valued clutter residue map. The remaining large values are clutter break-through.

The user supplied value, Xcr, in the map utilization algorithm is specified to permit regulation of the clutter break-through rate. The use of this parameter will have the effect of increasing the map values relative to the measured data values. The map value will then be equal to a higher percentile value of the random process' probability distribution. A higher map value reduces the probability that a clutter residue time sample will be interpreted as valid. The net result is a lower break-through rate.

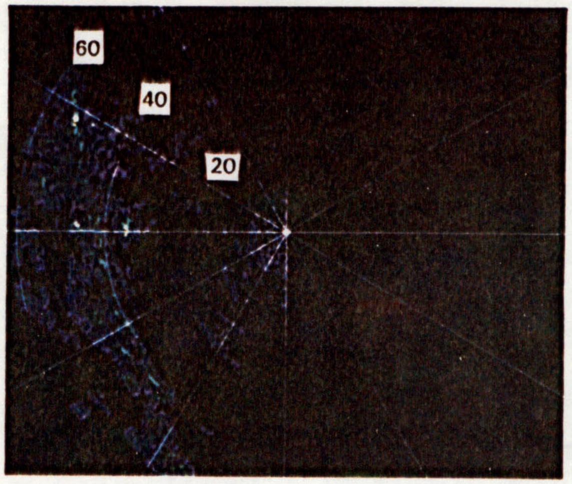


Figure 4-1. Clutter residue map of the area surrounding Stapleton Airport near Denver, CO.

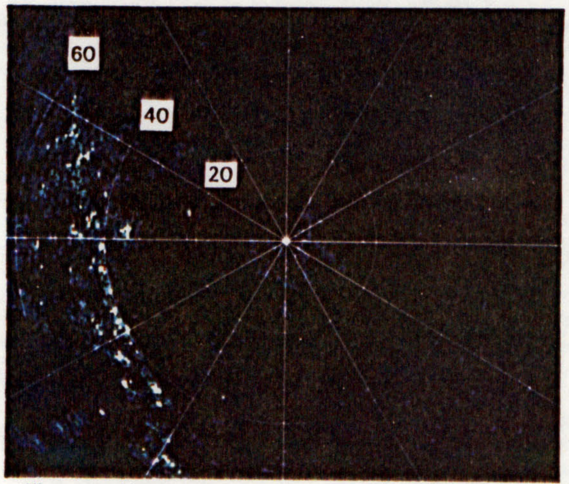


Figure 4-2. Clutter residue break-through resulting from editing clutter residue data with mean value clutter residue map.

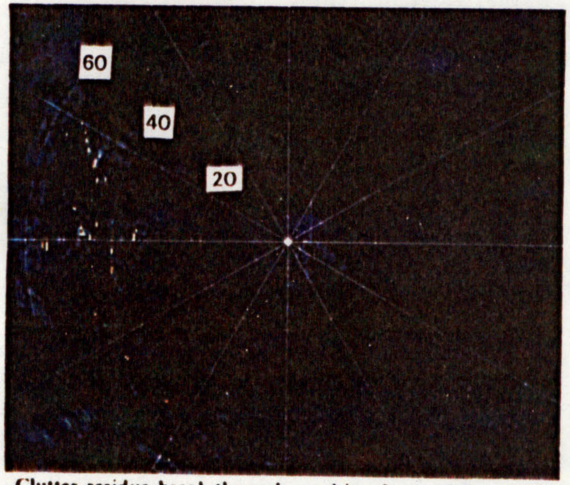
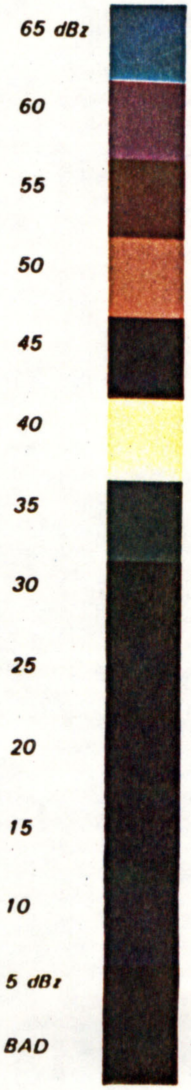


Figure 4-3. Clutter residue break-through resulting from editing clutter residue data with a value of 8 dB for Xcr.



Studies of S-band clutter measurements with an ASR-8 in Huntsville, AL by Mark Weber of Lincoln Laboratory [Weber, 1987] have shown that the significant temporal fluctuations of clutter (for a weather radar) vary in an interscan time period. M. Weber has suggested modeling the time behavior of the clutter signal from an individual range-azimuth cell with the non-central Gamma density function:

$$p(x) = \frac{1}{2\sigma^2}\left(\frac{x}{\lambda}\right)^{\frac{M-1}{2}} \exp\left(\frac{-x-\lambda}{2\sigma^2}\right) I_{M-1}\left(\frac{\sqrt{x\lambda}}{\sigma^2}\right) \qquad (1)$$

where,

I_{M-1} = the modified Bessel function of the first kind, order M-1.

σ = RMS power of the fluctuating component.

M = number of independent samples in a CPI (for interscan fluctuations M=1).

This model was used to fit clutter measurements made with an ASR-8 radar. The parameter λ in the non-central Gamma density function was estimated for several small clutter patches. His results suggested that a multiplicative factor of 8 dB above the mean value would limit the probability of the instantaneous clutter magnitude exceeding the threshold to 0.001. On average, this would results in one clutter break-through for each thousand gate radial. Due to the spatial continuity requirements of the wind shear algorithms, a clutter break-through rate of this magnitude would be tolerable. Similar results were experimentally determined with the ASR-9 radar's filter selection clutter map.

This model should also be applicable for determining values for Xcr provided that the clutter residue has the same statistical variation as the clutter itself. Figure 4-3 shows the same scan as in figure 4-2 after processing it with the algorithm in section 3.3 and a value of 8 dB for Xcr. The break-through rate has been significantly reduced. The majority of the Frontal Range to the west of the radar has been eliminated from the data. The remaining clutter break-through is nonhomogeneous and thus has a lesser impact on the wind shear detection algorithms which have a capability built in to reject isolated velocity anomalies [Merritt, 1987A].

An important result to note is that the clear air measurements remain intact. The algorithm has the ability to eliminate clutter and enhance the appearance of clear air measurements. This quality is necessary when trying to detect wind shear events with little or no moisture content. An example of such events are the so-called dry microbursts which happen frequently in the Denver area.

A principal objective of a clutter residue editing system is to reduce the number of false wind shear alarms reported by automated detection algorithms. The false wind shears are typically caused by anomalous zero velocities introduced by clutter in an otherwise even wind pattern. At our Denver site, a large number of the gust front reports are due to "line" clutter returns from the mountains to the west of the radar. Figure 4–4 displays weather data measured during 1987 with the FL–2 radar using high pass clutter filters with an overlay of the output of the gust front algorithm. Several convective storms are present with a fragmented gust front slightly East of the radar, running North to South. The algorithm reported a true detection in the northern section of the scan along with a false detection 40 kilometers to the South West. Due to the fragmentation of the gust front line and the radial orientation of the lower half, the tail section to the south was not detected by the gust front algorithm.

An edited version of this weather data set is displayed in figure 4–5. The clutter map presented in figure 4–1 was used with a value of 8 dB for Xcr. The false wind shear cause by clutter residue was eliminated. Furthermore, the storms in the north west sector and the true gust front tail to the South were not effected by the editing algorithm.

In this example, then, the algorithm fulfills the main objective of reducing the number of false alarms caused by clutter residue. Furthermore, it has achieved this while not affecting the surrounding clear air measurements.

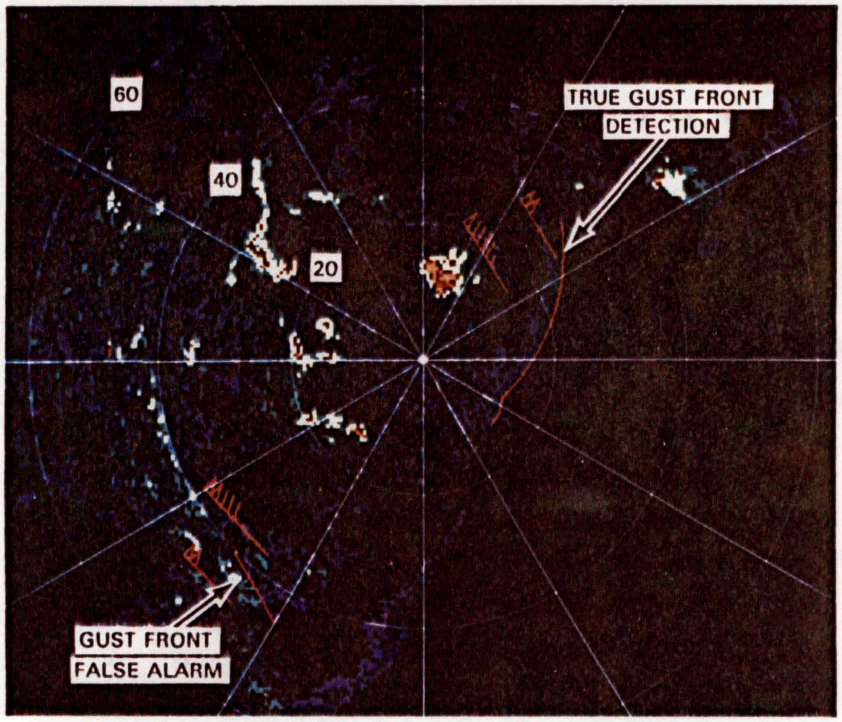


Figure 4-4. Gust front algorithm output overlaid on weather data collected with the FL-2 radar using a high pass filter.

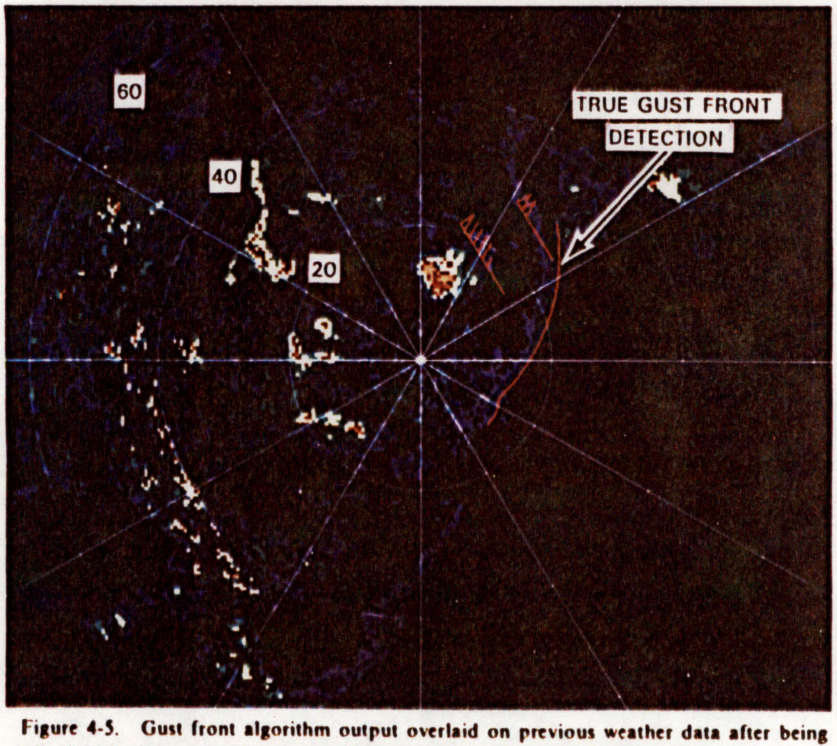
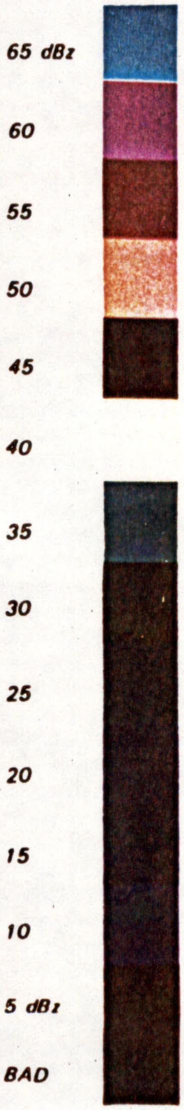


Figure 4-5. Gust front algorithm output overlaid on previous weather data after being edited with clutter residue map of Figure 4-1 and a value of 8 dB for Xcr.



5. Future Work

There are many issues which remain to be addressed in depth. While the concept of clutter residue map editing has been demonstrated to be a useful approach to reducing clutter in a TDWR type radar configuration, further improvements need to be made. These improvements include updates to the prototype implementation at Lincoln Laboratory, efforts to optimize the site adaptable parameters and further quantization and scoring of the editing algorithm results.

The current implementation at the laboratory is designed for off-line use. A real time version of the editing algorithm described in section 3.3 is under design. The current implementation is also very interactive. This feature proved useful for developmental and experimental purposes. Now that some experience has been gained, a more automated version which could be used for batch processing is being developed. Such an automated version would speed the construction of clutter maps and the processing of weather data thus providing a data base of edited data. A data base of edited weather data would aid in the refinement of this and other TDWR algorithms.

The are many issues that need to be addressed in order to optimize the algorithm. The magnitude fluctuations of the clutter is one of these issues. This variation in clutter levels impact the algorithm by increasing the number of clutter measurements which pass through the editor. These measurements are called clutter break-through. The break-through rate is regulated by two means, regularly updating the clutter residue map and by increasing the map threshold.

The optimal time between clutter map updates needs to be investigated. Ideally, one would like to update the clutter residue map whenever possible. This is not operationally practical, however, due to the time and resources required to construct a new clutter map. There has to be a balance between accurately measuring the state of the surrounding clutter environment and overburdening the service technicians. Seasonal clutter data from the Huntsville, Al, and Denver, CO, sites can be used to study the long term time fluctuation of clutter residue.

Another method to reduce the clutter break-through rate is with the threshold parameter, Xcr. This parameter is used to increase the amount with which each data measurement must exceed the corresponding clutter map value before the data is considered valid. However, there is a tradeoff between reducing the clutter break-through rate and limiting the amount of over editing of the weather data. The determination of an optimal value for

Xcr is dependent on the temporal distribution of the clutter residue, the wind shear detection algorithm's method of handling isolated anomalous velocities and the spatial distribution of the residual clutter.

The spatial clutter distribution plays two roles. First, the decision of what is an acceptable clutter break-through rate is dependent on the spatial characteristic of the clutter. A higher break-through rate is tolerable if the clutter residue occurs in a random pattern. This is due the isolated nature of the anomalous zero velocities which are interpreted similarly to noise. A spatially dependent clutter environment in which clutter appeared in clumps may require a lower break-through rate. This is due to the grouped nature of the anomalous velocities which may be interpreted as a coherent weather signature. Second, the ability to detect low reflectivity wind shear events is dependent on the spatial homogeneity of the clutter.

The issue of spatial dependency of clutter needs to be addressed. The clutter residue map editing algorithm was based on the theory that the clutter environment has a high degree of spatial variance due to local clutter shadowing. The concept of such an editing system is to resolve and remove large isolated clutter sources in an effort to enhance "inter-clutter" visibility. Homogeneous areas of moderate to high clutter residue levels would significantly reduce the ability to detect and measure low reflectivity wind events. The performance of the editor is based on the spatial variance of the clutter as well as the effect of the clutter break-through on the detection algorithms.

A method of quantifying or scoring the algorithm's performance needs to be developed. Initial measures include quantifying the impact of clutter on the measurement of low reflectivity wind shear events. An ultimate measure would rate the ability of the system to improve the performance of the wind shear detection systems.

While work on the clutter residue editing algorithm is still in progress, the usefulness and performance of this system has been demonstrated. Such an editing system can significantly reduce residual clutter without eliminating clear air measurements and enhance the performance of the wind shear detection algorithms. Furthermore, the clutter residue editing system will prove to be more effective as the site adaptation parameters are optimized and the update strategy is refined.

REFERENCES

Crocker, S.C., "TDWR PRF Selection Criteria", MIT Lincoln Laboratory Project Report ATC-147, Rpt. No. DOT/FAA/PM-87/25, To Be Released.

Doviak, R.J., Zrnic, D.S., *Doppler Radar and Weather Observations*, Academic Press Inc., Orlando, FL, 1984.

Evans, J.E., "Ground Clutter Cancellation for the NEXRAD System", MIT Lincoln Laboratory Project Report ATC-122, October 19, 1983.

NEXRAD Joint Systems Program Office, "NEXRAD Technical Requirements", R400-SP301, January, 1, 1986.

FAA, "Specification Terminal Doppler Weather Radar", U.S. Department of Transportation, Federal Aviation Administration, FAA-E-2806, October, 6, 1987.

Mann, D.R., Evans, J.E., Merritt, M.W., "Clutter Suppression for Low Altitude Wind Shear Detection by Doppler Weather Radars", *23rd Conference on Radar Meteorology*, Snowmass, CO, September 21, 1986.

Merritt, M.W., "Automated Detection of Microburst Windshear for Terminal Doppler Weather Radar", *Digital Image Processing and Visual Communications Technologies in Meteorology*", Cambridge, MA, October 26, 1987.

Merritt, M.W., Campbell, S.D., "Microburst Detection Algorithm", MIT Lincoln Laboratory Project Report ATC-145, Rpt. No. DOT/FAA/PM-87/23, To Be Released.

Merritt, M.W., Campbell, S.D., "TDWR Scan Strategy Description", MIT Lincoln Laboratory Project Report ATC-144, Rpt. No. DOT/FAA/PM-87/22, To Be Released.

Nathanson, F.E., *Radar Design Principles*, McGraw Hill, New York, New York, 1969, pp 258-268.

Sanford, P., Witt, A., Smith, S., "Gust Front/Wind Shift Detection Algorithm", MIT Lincoln Laboratory Project Report ATC-146, Rpt. No. DOT/FAA/PM-87/24, To Be Released.

Skolnik, M.L., *Introduction to Radar Systems*, McGraw Hill, New York, New York, 1980, pp 489-497.

Weber, M.E., "Ground Clutter Processing for Wind Measurements with Airport Surveillance Radars", MIT Lincoln Laboratory Project Report ATC-143, Rpt. No. DOT/FAA/PM-87/21, To Be Released.