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CLUTTER SUPPRESSION FOR LOW ALTITUDE WIND SHEAR DETECTION BY DOPPLER WEATHER RADARS*

D.R. Mann
J.E. Evans
M.W. Merritt

M.I.T. Lincoln Laboratory
P.O. Box 73
Lexington, MA 02173

1. INTRODUCTION

Low altitude wind shear (LAWS) has been recognized as a major cause of commercial airline aircraft accidents in the United States. The FAA is actively conducting the Terminal Doppler Weather Radar (TDWR) program to detect and identify dangerous wind shear events by measuring wind fields at and around airports using Doppler radar techniques. Clutter poses a major challenge to successful operation of such a system due to the need to measure the return from low cross section wind tracers in the presence of close-in clutter from stationary objects.

The paper describes the overall LAWS detection scenario with particular emphasis on microburst and gust front detection before presenting detailed experimental and analytical results on the suppression of ground clutter using a combination of:

1) subclutter visibility in excess of 50 dB by the use of high pass digital filters with narrow stopbands, and
2) interclutter visibility (ICV) algorithms which utilize the spatially distributed nature of the weather phenomena being measured, and
3) pencil beam antennas with readily achievable sidelobes.

2. WEATHER PHENOMENA OF CONCERN

The principal low altitude wind shear phenomena of concern of aviation operations is the microburst/downburst. This phenomena has been discussed extensively in the books by Fujita (1,2) and in papers at past Radar Meteorology conferences. Hence, we will only discuss those microburst features of greatest concern from the viewpoint of automated detection.

Although the microburst arises in the upper regions of convective storms, the observation of surface winds in microburst phenomena is of great importance since these winds form the most reliable indication of the presence and magnitude of the hazardous event.*

The microburst outflow is particularly challenging to detect using microwave weather radars due to:

1) the low altitudes of the outflow (typically 300m - 1 km above ground level (AGL) with peak velocities some 75 m above ground),
2) the small horizontal scale associated with the initial outflow (typically 1 km in diameter),
3) the low reflectivities (as low as 0 dBz) which can occur with operationally significant microbursts, and
4) the rapid time evolution of the outflow from initial occurrence to full strength (typically 5 minutes with development time ranging from 2 to 10 minutes) in relation

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to typical volume scan times of 1-2 minutes.

Low reflectivity microburst events are relatively more common in a high plains environment (e.g., Denver) due to evaporation in dry subcloud environments, but even moist subcloud environments such as Memphis, TN can have low reflectivities in the outflow region (11).

Gust fronts (4,5) are also of concern both from the viewpoint of safety and because they typically result in a wind shift which may occasion a change in runway usage (3). Gust fronts can have reflectivities as low as those postulated for microbursts, but typically extend to greater heights (1 to 3 km AGL), have longer life times and a greater horizontal extent.

3. LAWS DETECTION WITH THE TDWR

The principal candidate system for automated real time LAWS detection uses a NEXRAD-like ground based pulse Doppler pencil beam radar operating at S- or C-band. The strawman system typically has a 0.5 to 1. degree beamwidth with sidelobes of -25 dB to -35 dB, 1 s pulses, 1 kw of average power (from a klystron) and operate at PRF values consistent with adequate velocity unfolding. It can be shown that such a system with at least the NEXRAD sensitivity should have adequate signal to noise ratio for the postulated LAWS events over the coverage region described below.

The TDWR system is to provide reliable detection of microburst outflows (and hopefully, adequate warning) within a 10 km radius of the airport with 20 minute warning of the arrival of gust fronts. The 10 km radius is derived from the need to improve safety for aircraft which are less than 330 m AGL. The gust front/wind shift warning objectives may necessitate detection of gust fronts at ranges up to 30 km from the airport.

The major siting options are shown in figure 1. On airport siting is advantageous from the viewpoint of land acquisition and headwind/tailwind shear estimation, but may encounter significant difficulties in precursor detection due to the large angular region which must be scanned. Off airport siting (typically some 10-20 km from the airport) facilitates precursor detection, but would necessitate infering headwind/tailwind shear estimates in some cases for airports which have a variety of runway orientations. Off airport siting is currently the preferred option.

The scan strategy for LAWS detection is currently being refined. However, it is clear that PPI scans will be made at several adjacent elevation angles near the horizon as well as at certain other elevation angles. At least one full 360 degree PPI scan will be made every 5 minutes for gust front/wind shift detection and tracking.

4. THE CLUTTER CHALLENGE

Weather parameter (i.e., reflectivity, mean radial velocity and the radial velocity spectrum variance) are discussed in Doviak and Zrnic'(6). For the autocorrelation estimators typically used the "worst case" signal to clutter ratio (SCR) required for a velocity accuracy is approximately +10 dB (6).

The subsequent discussion of ICV will show why distributed clutter is of concern rather than point clutter. For the beamwidths, pulse widths and radar ranges of interest, the received clutter power is given by:

$$P_c = \frac{K\ P_t\ \lambda^2\ G_c^2\ \tau\theta}{R^3}\ \sigma_o \qquad (1)$$

where P_t is the transmitted power, K a constant, θ the beamwidth, R the range, λ the wavelength, G_c the antenna gain toward the clutter region and σ_o the clutter scattering cross section in m^2 per m^2 (7). Using eq. (1) together with the standard weather radar equation (6), it can be shown that the SCR is given by:

$$SCR = K\ \theta\ G^2 R\ \eta\ /\ (G_c^2\ \sigma_o) \qquad (2)$$

where G is the antenna gain, K a constant, and η the weather volume reflectivity. Figure 2 shows the SCR at various ranges at S-band for a 1 deg. beamwidth antenna with mainlobe clutter ($G_c = G$). Measurements of the scattering cross section have been carried out using the FAA transportable testbed Doppler weather radar (FL-2) (10), an X-band clutter measurement system (8), and FAA ASR-8 systems (14), Figure 3 shows representative results. The various Memphis area results illustrate the substantive sensitivity to radar siting and marked inhomogeneity of clutter at a given site. Based on these measurements and the literature (5), we are currently using a σ_o value of -40 dB to represent a

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*There are a number of microburst features at upper levels of a storm (e.g., descending reflectivity cores, rotation and convergence) which are associated with some microburst; however, the reliability of such features for unambiguous microburst recognition is unclear at this point in time.

stressful clutter environment. In such an environment, approximately 65 dB of clutter suppression is required at 10 km range for a 0 dBz weather target.

5. CLUTTER MITIGATION

The four major clutter suppression techniques under investigation are:

1) siting to avoid illuminating clutter in the critical region about the airport,

2) filtering in the angular domain via the antenna pattern,

3) filtering in the time domain at each range gate to reject targets at near zero velocity, and

4) clutter residue map based editing of the clutter filter outputs.

Siting the system so that clutter sources in the critical regions are shielded by intervening obstacles will be possible at many airports. However, it cannot be relied on near major cities (e.g., New York) as there may be very few available sites.

Since the microburst outflow typically extends to above 200 m AGL, at close range (e.g., less than 4 km with a 1 deg. beamwidth), it should be possible to detect the weather target in the mainbeam while having the ground clutter illuminated by the pattern sidelobes. Figure 4 compares the measured clutter as a function of elevation angle above a hill near the FAA/Lincoln Laboratory testbed S-band radar (FL-2) Huntsville, AL site (12) with the two way sidelobe pattern of the antenna. We see that an effective suppression of over 55 dB is obtained when the clutter is in the sidelobe region.

Clutter suppression by the use of high pass digital filters has been previously described in reports and meetings of this conference (9,10). It was shown that 50 dB of clutter suppression can be achieved against isolated fixed targets. The operational utility of such filters for the rejection of ground clutter with minimal impact on MB detection was demonstrated in the recent LAWS measurements in Memphis, TN (11). However, the practical suppression achievable against a stressful environment with trees moving in the wind, etc. has not been fully quantified.

Figure 5 compares the probability distribution of the effective clutter scattering cross section (measured in equivalent reflectivity units of dBz) at the input and output of a representative clutter suppression filter for data from the principal measurement region for the MIST program (12) in Huntsville, AL. A reduction of approximately 35 dB is achieved in the upper range of quantiles (e.g., 50-90%). It should be noted that this shift is biased downward somewhat by the clear air return (i.e., the clutter suppression filters typically can reduce the clutter return down only to the level of the clear air return).

Figure 5 also shows a small number of clutter cells which are only weakly suppressed by the filter. To reject these anomalous points and take advantage of "microshadowing" within apparently homogeneous clutter regions, a clutter residue map (developed during periods of good weather) can be applied to the output of the clutter filters. The concept (which is used in the ASR-9 weather channel (14)) is to compare the filtered output with the stored map value and reject the data if the reflectivity estimate is not sufficiently larger than the map value.

The performance of this editing process (hereafter abbreviated CME for clutter map editor) has been assessed by analysis of experimental data and by analytical studies (13). In evaluating the detection performance improvement with the CME, it is assumed that the detection process makes use of the spatial continuity of microburst events over suitable spatial scales. If the net clutter contribution is reduced over a two-dimensional patch of space (approximated by a cartesian bin), then the detection process is assumed to improve correspondingly. Although the current microburst outflow signature detection methods rely on high resolution polar format velocity measurement, spatial integration is still an important element*.

Measured clutter distributions can be approximated reasonably well by a Weibull distribution characterized by a median value, m and a slope parameter a (a=1 corresponds to a Rayleigh distribution while values of a greater than 1 have a greater fraction of large values than would be expected with a Rayleigh distribution). It can be shown that the minimum of n independent samples from a Weibull distribution has a Weibull distribution with the same slope, but a mean which is smaller by a^{-n}.

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*Investigations of the microburst detection algorithm performance with distributed missing data points is currently in progress.

This property suggests that CME can achieve a clutter suppression of a^{-n}. However, to maintain a fixed Cartesian resolution in the CME output, the number of samples combined, n, will decrease with range. Figure 6 compares the average and minimum clutter residue levels in 250 m x 250 m Cartesian cells for the principal FLOWS measurement region. The high quantile values are reduced by some 18 dB which agrees reasonable well with the analytical prediction of 20 dB at the mid-range for a slope a of 4.

6. SUMMARY

This paper has discussed the principal clutter suppression techniques under active investigation for use in the TDWR program. The mainbeam clutter challenge to microburst outflow detection is seen to be quite challenging and a variety of techniques in addition to the use of high pass filters may be required at difficult sites. These various options have proven adequate for the clutter environments encountered by FL-2 to date; however, work to refine the clutter suppression capability is continuing.

The FAA currently plans to use NEXRAD system as interim TDWR systems with a separately procured C-band system as the final TDWR. It appears that the increase in frequency will reduce the required clutter suppression by approximately 10 dB due to the increase return form the weather scatterers. Additionally, C-band offers the possibility of utilizing 0.5 degree beamwidths so as to extend the range over which mainlobe clutter can be avoided in detecting microburst outflows. The appropriate mix of the techniques discussed above for a C-band TDWR will be developed this coming year and validated in a series of measurement programs in the 1988-91 time frame.

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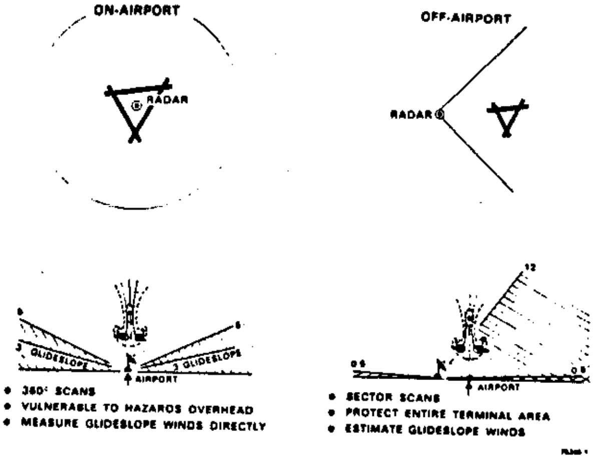

Fig. 1. TDWR Siting Options.

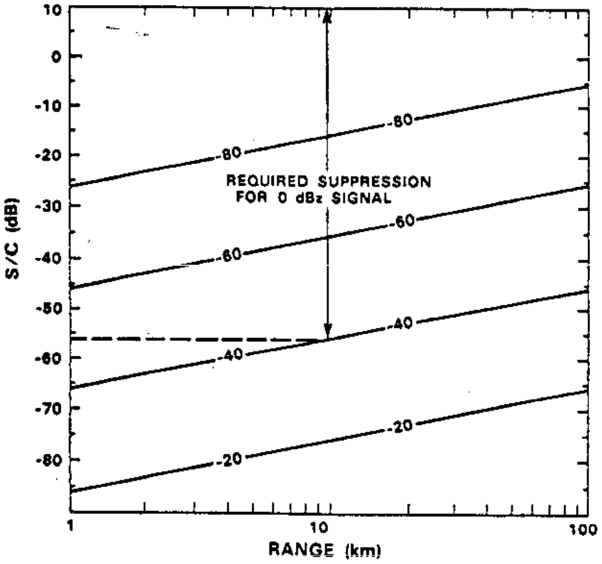

Fig. 2. SCR vs. Range for Various σ_0.

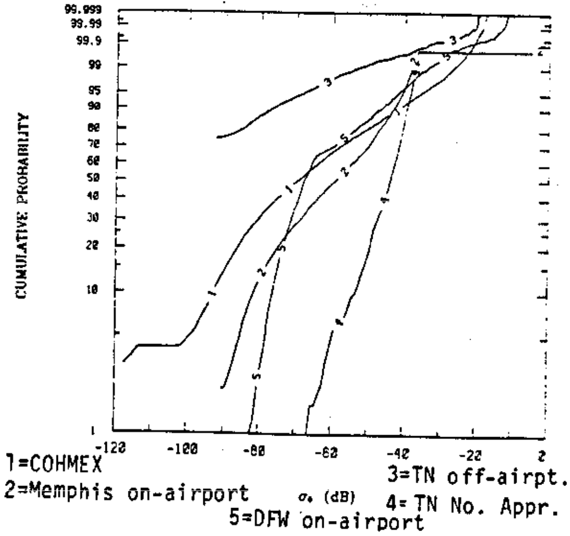

Fig. 3. Clutter Cross Section Distributions.

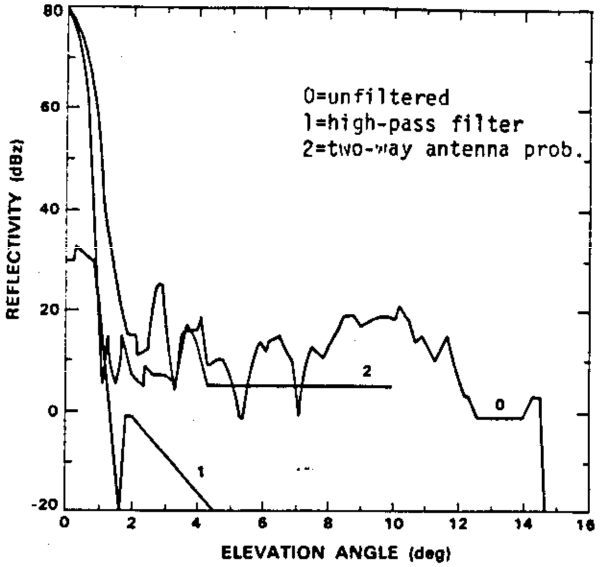

Fig. 4. FL-2 Site Clutter Level vs. Elevation.

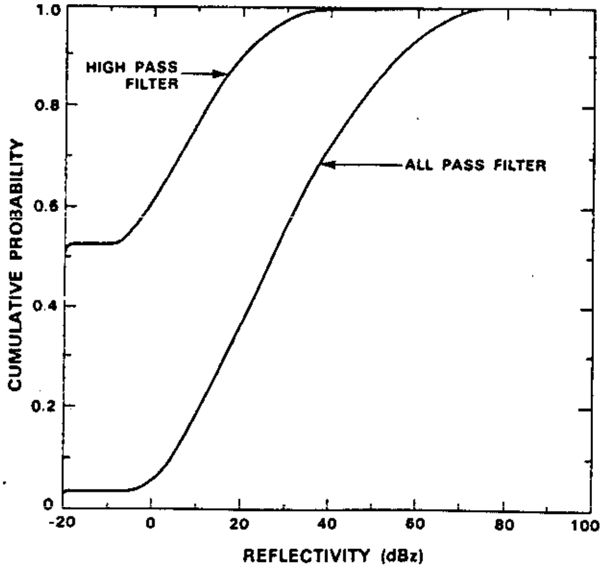

Fig. 5. Distribution of Clutter Over MIST Measurement Region.

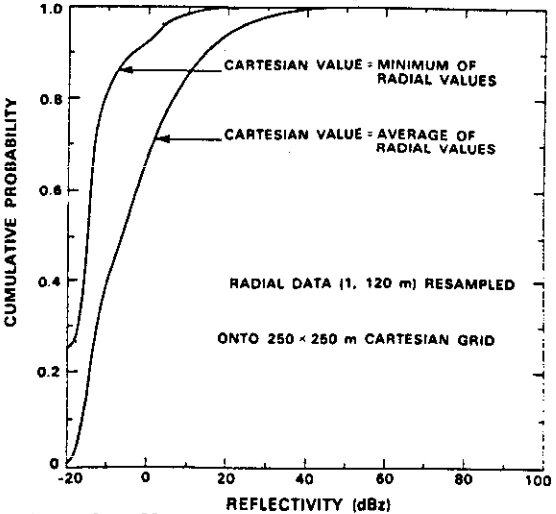

Fig. 6. Clutter Cross Section Residue Over MIST Measurement Region.