GROUND CLUTTER DETECTION AND ELIMINATION FOR DUAL-POLARIZED WEATHER RADAR USING MULTIPARAMETER THRESHOLDS

Liu, Li

Radio Engineering Department
South China University of Technology
Guangzhou, 510641, P.R.China
e-mail: ecliliu@scut.edu.cn

V. N. Bringi

Electrical Engineering Department
Colorado State University
Fort Collins, CO 80523, USA
e-mail: bringi@lance.colostate.edu

ABSTRACT

In this paper we described the ground clutter effects on polarimetric radar parameter estimations using non-spectral approach. A simple but efficient technique for detecting and eliminating ground clutter effect on polarimetric radar measurements using multiparameter thresholds is derived based on tremendous data processing and analysis. Some typical examples are given for illustration and interpretation.

1. INTRODUCTION

Ground clutter is generally defined as radar return from non-meteorological, ground-based targets. Clutter contamination often adversely affects the accuracy of the reflectivity-based or polarized radar parameter estimates. Clutter-induced bias of base data not only brings into question the reliability of data presented in the base products, but also a detrimental effect on all meteorological parameter estimation algorithms. Numerous methods of minimizing such data contamination through filtering and noise reduction have been employed for radar data analysis (Chrisman et al., 1994).

In this paper we discuss the technique to detect and eliminate ground clutter effect for multiparameter meteorological radar, such as a dual-polarized Doppler radar, with multiparameter thresholds including those based on signal-noise-ratio (SNR), co-polar correlation coefficient (ρhv(0)), Differential Reflectivity (Zdr), and differential phase (Ψdp). The intention is to estimate the rainfall rate accurately derived from corrected differential propagation phase and avoid misleading information from other parameters when the signal from rain is contaminated by ground clutter. The radar measurements were collected with a dual-polarized S-band weather radar CSU-CHILL which is a research and education facility of the US National Science foundation, operated by Colorado State University and located near Greeley, Colorado in the USA.

2. GROUND CLUTTER EFFECT ON POLARIMETRIC PARAMETER ESTIMATION

Ground clutter targets, by the very nature of their composition, are very efficient reflectors of electromagnetic energy. The innate ability of ground clutter targets to reflect more energy than nearby meteorological targets allows the clutter return to dominate the returned energy (power) for the affected range bin.

a. Reflectivity **(Z).** Reflectivity is the measure of the efficiency of a target to reflect (absorb and re-radiate) radar energy. In general, clutter contamination will cause significantly higher reflectivity estimates because of the highly reflective nature of ground targets and the dependence of reflectivity (Z) on the magnitude of the returned power.

b. Differential Reflectivity **(Zdr).** For a dual-polarized radar, the differential reflectivity Zdr is estimated as a ratio of the horizontal reflectivity (Zh) over the vertical reflectivity (Zv). Zdr value based on measurements from rain drops should be positive, while in ice region it is close to zero. Clutter contamination causes Zdr to fluctuate noisily from range bin to range bin.

c. Differential Phase **(Ψdp).** Ψdp is a measurement of the phase difference between HH (horizontally transmitted and received) co-polar echo and VV (vertically transmitted and received) co-polar echo. It is a composite of *differential backscatter phase* (δ) and *the two way differential propagation phase* Φdp. δ is a function of particle size, shape, composition and orientation. The slope of Φdp is an important indication of rainfall rate. When ground clutter is present, Ψdp fluctuates dramatically from range bin to range bin due to large changes in abnormal δ.

d. Copolar correlation coefficient **ρhv(0).** ρhv(0) is defined as the zero lag correlation coefficient between horizontally (HH) and vertically (VV) transmitted and received co-polar signals. It is a useful parameter in application towards hail sizing, improving polarization estimates of rainfall, and the melting level detection in both convective and stratiform precipitation. But in the presence of ground clutter, ρhv(0) value drops and fluctuates significantly.

e. Linear depolarization ratio **(LDR).** LDR is a measure of the ratio of cross-polar and co-polar powers, which is sensitive to shape, size, orientation or canting angle distribution (mean and variance), wetness and composition of the scatterers. Echoes from ground clutter will be depolarized so that LDR tends to be high.

3. MULTIPARAMETER THRESHOLDING TECHNIQUE

Based on the analysis of large amount of multiparameter radar measurements (Liu et al, 1993, 1994) and observations of ground clutter effects on polarimetric parameter estimations, we use signal-noise-ratio SNR, the slope change of differential phase Ψdp, the estimated mean and standard deviation of co-polar correlation coefficient ρhv(0) and Zdr as multiparameter threshold criterion to detect the ground clutter. Since reflectivity as well as signal-noise-ratio can be very high in the presence of ground clutter, but Ψdp changes rapidly and significantly, the mean ρhv(0) is very low and its standard deviation is big, the mean Zdr can be negative and fluctuates extensively from range bin to range bin, we use empirical multiparameter thresholds based on all three parameters.

For a certain range bin (or, range gate) along the range profile of radar measurements, if SNR > 50 dB, but
1) mean [ρhv(0)] < 0.8
   and
   SD[ρhv(0)] > 0.05,
where mean[ρhv(0)] and SD[ρhv(0)] are the estimated mean value and standard deviation (SD) of ρhv(0) based on three consecutive points of ρhv(0) along the range profile;
and / or
2) mean [Zdr] < -2,
   and
   SD[Zdr] > 1;
and / or
3) | slope(Ψdp) | > 50 °/2Δr,

then we classify the multiparameter estimates based on the measurements at this range bin as ‘bad data’ due to ground clutter contamination. For ρhv(0), Zdr and LDR, we simply clean the clutter contaminated by ‘bad data’ flag, set the ‘bad data’ as certain constants far away from normal value ranges, respectively. But for Ψdp, we substitute the ‘bad data’ with a straight line, linking the 3-point averaged Ψdp value (which is low pass prefiltered for reducing high frequency fluctuations) at the end of previous ‘good’ data segment and that at the beginning of next 'good' data segment. In this way the clutter contamination effect causing anomalous *differential backscatter phase* δ is successfully eliminated while *the two way differential propagation phase* Φdp which is monotonically increasing in rain media can be preserved and used for further estimating the *specific differential phase* Kdp (half of the slope of Φdp and rainfall rate (Aydin et al, 1995).

4. EXAMPLES

The given example shown in figure 1-a through 1-e is based on the same data set collected by CSU-CHILL radar on June 7, 1995, in Colorado, USA. It shows the range profiles of reflectivity Zh, signal-to-noise ratio SNR, differential phase Ψdp, two way differential propagation phase Φdp, linear depolarization ratio LDR, intrinsic LDR (LDR_int), copolar correlation coefficient ρhv(0), differential reflectivity Zdr, and the corrected ρhv(0)_new and Zdr_new along the radar beam with antenna azimuth fixed at 195.7 degree and elevation at 0.5 degree (very close to ground).

It can be seen that two groups of ground clutters were detected in the range segments of 14 ~ 18.5 km and 23.5 ~ 26.5 km, respectively. In the range between 14 ~ 18.5 km, Zh > 25 dBZ and SNR (dashed line) > 50 dB, indicating that the noise effect to the radar measurements is not much in this range segment. But Ψdp fluctuates dramatically from -60 to 60 degree, LDR floats well above -20 dB appearing probable heavy hail existence, Zdr changes rapidly from range bin to range bin and then completely falls below -2 dB, and ρhv(0) drops to 0.7 and fluctuates extensively. According to our multiparameter threshold criterion, it is recognized that the radar measurements in this range segment were dominated by ground clutter and hence are treated as 'bad data'.

In the range between 23.5 ~ 26.5 km, Zh > 35 dBZ and SNR > 50 dB, indicating that the signal is quite strong with little noise contamination. Ψdp appears big δ (~ 15 degree), and LDR values are quite high above -15 dB, as if there were big hail stones. But Zdr fluctuates dramatically around -2 dB and ρhv(0) fluctuates even more extensively than the previous 'bad' segment. Again, the radar measurements in this range segment is detected as contaminated by ground clutter.

LDR_int stands for 'intrinsic LDR' which is derived from LDR by forcing the 'bad data' to system noise level, say, - 40 dB for CSU-CHILL radar, and removing the attenuation effect in 'good data' segment. ρhv(0)_new and Zdr_new are the corrected ρhv(0) and Zdr by simply forcing the 'bad data' to certain values far away from normal value ranges, respectively. Φdp is adaptively filtered from Ψdp after the correction in the bad data segments by straight linking the end of the previous 'good data' segment and the beginning of the next 'good data' segment. Note that in the range between 14 ~ 18.5 km, 'bad data' of Ψdp were replaced by a flat straight line, indicating the measurements were dominated by ground clutter, while in the range between 23.5 ~ 26.5 km, 'bad data' of Ψdp were substituted by an increasing straight line, showing that a signature of rainfall is extracted and can be estimated out of clutter contamination.

5. CONCLUSIONS

For dual-polarized weather radar, ground clutter contamination can be successfully detected and eliminated by using multiparameter thresholds, based on the comprehensive physical analysis of overall multiparameter radar measurements, thus avoiding the misleading interpretations or confusions.

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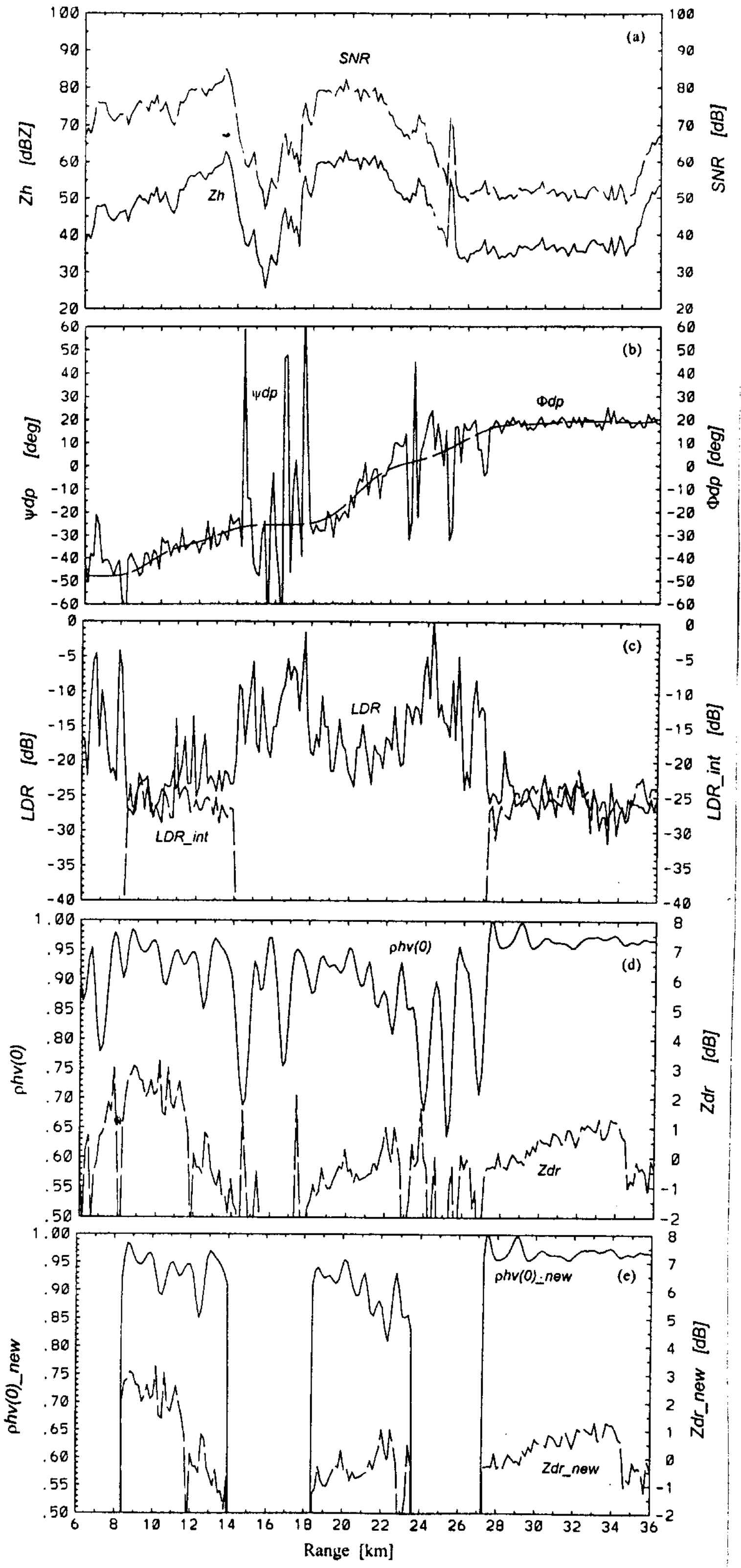

Figure 1: Range profiles of
(a) Zh and SNR;
(b) Ψdp and Φdp;
(c) LDR and LDR_int;
(d) ρhv(0) and Zdr; and
(e) ρhv(0)_new and Zdr_new measured by CSU-CHILL radar on June 7, 1995, with AZ=195.7 degree and EL=0.5 degree.