P11.B.13. GROUND CLUTTER RECOGNITION USING POLARIMETRIC SPECTRAL PARAMETERS

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1. *Introduction*

Ground clutter complicates interpretation of spectral moments and polarimetric variables, hence it is desirable to filter it out. Several approaches have been explored for the clutter filtering on single-polarization radars: prerecording clutter maps and then subtracting the residues (e.g., Steiner and Smith, 2002; Yo-Han Cho et al., 2006), applying Doppler filters (Siggia and Passarelli, 2004; Ice et al., 2004; Kessinger et al., 2003; Berenguer et al., 2006), and a combination of both as implemented on the WSR-88D network in the USA.

The US National Weather Service is planning to upgrade the WSR-88D radar network with dual polarization (Saffle et al., 2007). Thus significant new capability including recognition of echoes from ground clutter will become available. Thus far recognition of clutter was based on the values of polarimetric variables (e.g., Zrnic et al., 2001) and their texture, i.e., spatial variations of polarimetric parameters (Dixon et al., 2006). No attempts have been made to adaptively recognize the clutter and filtering it from the polarimetric radar signals. Herein, we describe an approach based on polarimetric spectral characteristics of dual polarization signals which allows adaptive clutter filtering at a single range location.

2. *The algorithm*

The algorithm for ground clutter recognition uses analysis of the Doppler spectra in a narrow band centered on zero at both polarizations. Three spectrum lines are supplied to the algorithm (Fig. 1). The full Doppler spectra at two polarizations are shown in Fig. 1a; the spectrum consisting of three lines centered at zero velocity is in Fig. 1b and the residual spectra are in Fig. 1c. In essence, the algorithm generates an "instantaneous clutter map" using the 3-line spectra. Pairs of dual polarization signals from single range locations are subjected to polarimetric spectral analysis.

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Four polarimetric variables are calculated using the 3-line spectrum: differential reflectivity ($\tilde{Z}_{DR}$), differential phase shift ($\tilde{\varphi}_{dp}$), copolar correlation coefficient ($\tilde{\rho}_{hv}$), and the power ($\tilde{P}_h$). Radar parameters for the full spectrum are denoted as Z_{DR}, φ_{dp}, ρ_{hv}, and P_h. Definitions of these variables can be found in Doviak and Zrnic (1993). 3-line spectra are recorded at short pulse repetition times of the WSR-88D and occupy velocity interval between -0.6 and 0.6 m s^{-1}. The Von Hann spectral window has been applied on the time series data. The statistics of polarimetric variables obtained from clutter are quite different from the statistics of weather signals and that makes clutter recognition possible.

The algorithm compares measured polarimetric moments for the 3-line spectrum with threshold parameters $\tilde{Z}_{DR0}$, $\tilde{\varphi}_{dp0}$, $\tilde{\rho}_{hv0}$ if signal-to-noise ratio, $S\tilde{N}R_h$, at the range gate exceeds $S\tilde{N}R_{h0}$, i.e., clutter is recognized if

$$\tilde{Z}_{DR1} \geq \tilde{Z}_{DR} \geq \tilde{Z}_{DR2}, \text{ or} \quad (1)$$

$$\tilde{\rho}_{hv} \leq \tilde{\rho}_{hv0}, \text{ or} \quad (2)$$

$$|\tilde{\varphi}_{dp} - \overline{\varphi}_{dp}| \geq \tilde{\varphi}_{dp0}, \quad (3)$$

provided

$$S\tilde{N}R_h \geq S\tilde{N}R_{h0}. \quad (4)$$

where $\overline{\varphi}_{dp}$ is the differential phase (i.e., the propagation phase) at a given range location.

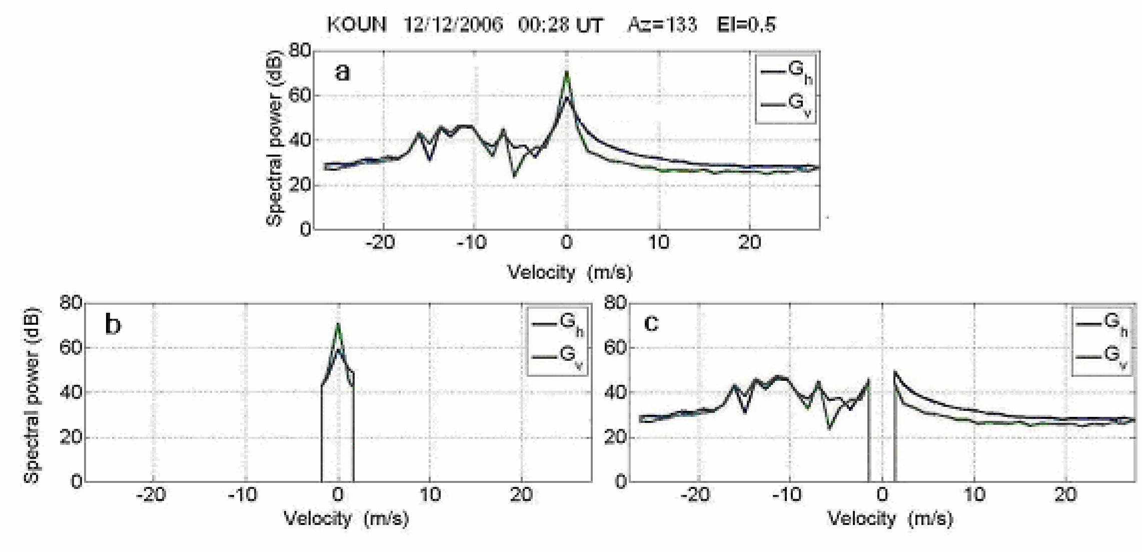

Fig. 1. (a) Doppler spectra at horizontal (the blue line) and vertical (the green line) collected in snowfall on 12 Dec. 2006; (b) the spectra obtained from the spectra in (a) by removing three spectral lines; (c) the three line spectra that are being removed from (a).

Inequality (4) states that signal should be sufficiently strong to avoid contamination by noise. In our experiments, we use $\widetilde{SNR}_h$ = 5 dB. Probability of clutter recognition via equations (1) to (3) depends on threshold parameters, therefore their values are critical. Observations with the KOUN indicate that hydrometeors' Z_{DR} is in the interval -2 to 5 dB. Negative Z_{DR} are observed at the tops of thunderstorms in electrified regions. For low elevation angles where clutter recognition is performed, -2 dB thresholds can be changed with -0.5 dB but rules (1)-(3) should be applied after a correction of Z_{DR} for attenuation is done. For now, we use a conservative threshold of -2 dB for Z_{DR}.

Measured correlation coefficients from ground clutter at a single range location can be very close to unity (Zrnic et al., 2006), i.e., they can be of a "hydrometeor" value. The same applies for $\tilde{\rho}_{hv}$ from the 3-line spectra. For hydrometeors, values of ρ_{hv} are close to unity and drop to 0.85 sometimes in hail or melting layer. The latter situation should not indicate clutter because the melting layer can be on the ground. Thus we choose $\tilde{\rho}_{hv0}$ = 0.8.

The differential phase in precipitation increases with distance from radar. Therefore the measured differential phase at a range gate is a superposition of the mean differential phase accumulated in precipitation and "intrinsic" backscatter differential phase. If the location has no clutter, the intrinsic differential phase is zero. For clutter, it varies significantly (Zrnic et al., 2006). Application of (3) requires measurements of the true differential phase. In clutter region, such measurements can produce errors due to clutter contamination. To avoid this, two approaches can be utilized. 1) In regions close to radar where clutter is often present, the true differential phase is close to the system differential phase which is known (Zrnic et al., 2006). 2) In regions with significant accumulated phase, it can be estimated in range locations where only weather is present. The latter leaves some questions on possible accuracy of such measurement so we have chosen a rather conservative threshold $\tilde{\varphi}_{dp0}$ = 20^o. Table 1 summarized the threshold used in this study.

Table 1. Threshold parameters used in clutter recognition

$\widetilde{SNR}_{h0}$, dB	$\tilde{Z}_{DR1}$ / $\tilde{Z}_{DR2}$, dB	$\tilde{\rho}_{hv0}$	$\tilde{\varphi}_{dp0}$, deg
5	-2 / 5	0.8	20

3. *Results*

The described algorithm for clutter recognition has been tested on WSR-88D KOUN situated in Norman, OK. The data have been collected with radar parameters listed in Table 2.

Table 2. Radar parameters of data collection

Elevation, deg	0.5
Antenna rate, deg s^{-1}	20
Number of samples	48
Azimuthal resolution, deg	1
Pulse repetition frequency, Hz	1013

The left column of panels in Fig. 2 presents the distributions of polarimetric parameters measured for the full and 3-linespectra at one 360-deg radar sweep on March 6, 2007. No weather echoes were recorded at the time. In the panels, the imposed thresholds are shown with the thick vertical lines. The arrows show regions where clutter is recognized in accordance with rules (1) – (3). For instance, 57.5% of measured $\tilde{Z}_{DR}$ have clutter values and the remaining 43.5% have "hydrometeor" values. Thus using $\tilde{Z}_{DR}$ only we can recognize clutter in only about half of range gates. Using $\tilde{\varphi}_{dp}$ and $\tilde{\rho}_{hv}$ alone the clutter is recognized in 83% and 63% of range gates. It should be noted that the distributions of the differential phases have been obtained applying a shift by system φ_{dp} and the propagation phase. Applying rules (1)-(3) simultaneously, probability of clutter recognition becomes 96.3% for the sweep. So we conclude that the algorithm recognizes clutter at single range locations with sufficiently high probability.

The right column of panels in Fig. 2 shows the distributions in precipitation. Normal clutter (i.e., in the absence of anomalous propagation) is observed on KOUN within 40 km. On Feb. 15, no anomalous propagation was observed and the data were processed at ranges beyond 40 km. The same rules, i.e., (1)-(3), have been applied to the data to obtain the false alarm rate, i.e., probability of clutter recognition in the absence of clutter. It is seen from the right panels that the single parameter has low false alarm rates of 1%, 1.9%, and 0.8% for $\tilde{Z}_{DR}$, $\tilde{\varphi}_{dp}$, and $\tilde{\rho}_{hv}$ correspondingly. Simultaneous application of the rules produces a 2.7% rate of false recognitions. The latter rate is higher than any rate indicated for the single parameter detection because rules (1)-(3) are applied in the "or" combination. The mean probabilities of clutter recognition and false alarms from August 2006 to April 2007 are nearly 97% and 3%. Analyzed data contains seven days (fifteen 0.5^{o}-elevation cuts) in "clear air" and tree days (seven 0.5^{o}-elevation cuts) with widespread precipitation.

4. *Conclusion*

The algorithm for clutter recognition based on polarimetric variables obtained from 3-lines of spectral densities demonstrates about 97% of correct clutter recognition and a false alarm rate of 3%. Thus, with further refinement it is worthy considering for generation of instantaneous "clutter maps". Simplicity and operation on signals from single range locations are in its favor. Furthermore, it is straight forward to immediately remove the clutter following recognition and obtained the spectral moments and the polarimetric variables with minimal additional computations. The algorithm should recognizes clutter caused by anomalous propagation. It can also prevent removal of weather signals in situations where precipitation has zero Doppler velocity.

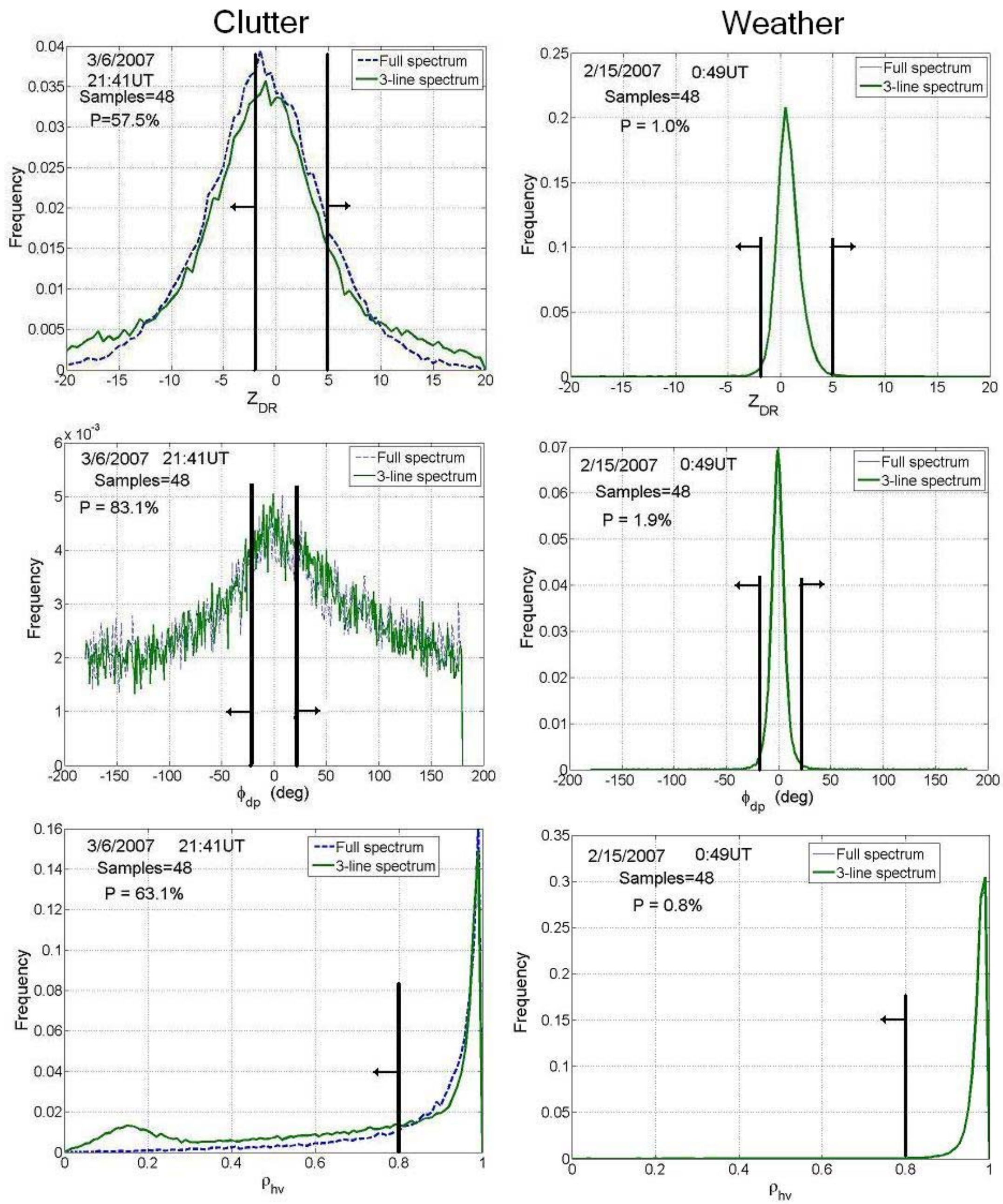

Fig. 2. Distributions of measured Z_{DR}, φ_{dp}, and ρ_{hv} for the full and 3-line spectra in (left column) clutter and (right column) widespread precipitation. The black vertical line show the threshold imposed by algorithm (1)-(3).

References

Berenguer M., D. Sempre-Torres, C. Corral, and R. Sanches-Diezma, 2006: A fuzzy logic technique for identifying nonprecipitating echoes in radar scans. *J. Atmos. Ocean. Technol.*, **23**, 1157-1179.

Dixon, M., C. Kessinger, and J. Hubbert, 2006: Echo classification within the spectral domain to discriminate ground clutter from meteorological targets. IIPS, P9.6.

Doviak, R. J. and D. S. Zrnic, 1993: *Doppler radar and weather observations*, 2nd ed., Academic Press, 562 pp.

Ellis, S., C. Kessinger, J. VanAndel, M. Dixon, and J. Hubbert, 2003: Enhansments in clutter/precipitation discrimination for the WSR-88D. IIPS 19, P2.9.

Ice, R.L., R.D.Rhoton, D.S. Saxion, N.K. Patel, D.A. Sirmans, D.A. Warde, D.L. Rachel, and R.G. Fehlen, 2004: Evaluation of the WSR-88D ORDA system signal processing. 20th IIPS.

Kessinger C., J. VanAndel, S. Ellis, G. Meymaris, 2003:The radar echo classifier: a fuzzy logic algorithm for the WSR-88D. 3rd Conf. Artif. Intell. Applic to Envir. Sci., AMS, 9-13.

Saffle, R. E., G. S. Cate, and M. Istok, 2007: NEXRAD Product Improvement—Update 2007. *23 Conf. on IIPS, Amer. Meteorol. Soc*., San Antonio, TX, paper 5B.1.

Siggia, A.D., and R.Passarelli Jr., 2004: Gaussian model adaptive processing (GMAP) for improved ground clutter cancellation and moment calculation. 3rd European Conf. Radar Meteorol. Hydrol.(ERAD), 67-73.

Steiner, M, and J.A. Smith, 2002: Use of three–dimensional reflectivity structure for automated detection and removal of nonprecipitating echoes in radar data. *J.Atmos. Ocean. Technol.*, **19**, 673-686

Yo-Han Cho, GyuWon Lee, Kyung-Eak Kim, and I. Zawadzki, 2006: Identification and removal of groung echoes and anomalous propagation using the characteristics of radar echoes. *J. Atmos. Ocean. Technol.*, **23**, 1206-1222.

Zrnic, D.S., A. Ryzhkov, J. Straka, Y. Liu, and J. Vivekanandan, 2001: Testing a procedure for automatic classification of hydrometeor types. *J. Atmos. Ocean. Technol.*, **18**, 892-913.

Zrnic, D.S., V.M. Melnikov, and A. V. Ryzhkov, 2006: Corellation coefficients between horizontally and vertically polarized returns from ground clutter. *J. Atmos. Ocean. Technol.*, **23**, 381-394.