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POSSIBILITIES FOR DEPOLARIZATION ESTIMATES USING SIMULTANEOUS TRANSMISSION AND RECEPTION SCHEMES IN POLARIMETRIC RADARS

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1. INTRODUCTION

Simultaneous transmission and simultaneous reception (STSR) of horizontally and vertically polarized radar signals is now being considered for the polarization upgrade of the existing network of WSR-88D weather radars. This measurement scheme has already been implemented with a few research radars, including the CSU-CHILL S-band radar and the ETL X-band radar. The STSR scheme offers a number of important advantages over traditional measurement schemes with fast pulse-to-pulse switching between h and v polarizations (Doviak et al. 2000). However, a straightforward estimate of depolarization (e.g., linear depolarization ratio -LDR) is not available with this scheme. Though depolarization is not directly used in estimates of rainfall, it is an important parameter in many algorithms for identification of types and mean shapes of hydrometers. This study considers prospects for depolarization estimates within the framework of the STSR scheme.

2. THEORETICAL CONSIDERATIONS

Accounting for propagation effects and assuming mean canting along the propagation path to be negligible, the transformation amplitude matrix is given as a multiplication of three matrices:

$$\begin{vmatrix} T_h & 0 \\ 0 & T_v \end{vmatrix} \begin{vmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{vmatrix} \begin{vmatrix} T_h & 0 \\ 0 & T_v \end{vmatrix} \qquad (1)$$

where transmission elements $T_h = (\Delta A_h)^{1/2}\exp(j\varphi_{DP}/2)$ and $T_v = (\Delta A_v)^{1/2}$ .These elements are expressed using the one way power attenuations (ΔA_h and ΔA_v) and the round-trip propagation phase difference $\Phi_{DP.}$ Φ_{DP} measurements can be somewhat biased by a differential phase on backscatter and by the dispersion of canting angles along the propagation path. These effects are expected to be small. The cross-polar scattering matrix elements are the same in the coordinates system adopted here ($S_{vh} = S_{hv}$).

One useful depolarization parameter is a circular depolarization ratio (C_{dr}), which can be shown to be:

$$C_{dr}=\langle|S_{hh}A_{hv}\exp(j\Phi_{DP})+2jS_{hv}A_{hv}{}^{1/2}\exp(j\phi_{DP}/2)-S_{vv}|^2\rangle \,/\, /\langle|S_{hh}A_{hv}\exp(j\Phi_{DP})+S_{vv}|^2\rangle\,, \qquad (2)$$

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where the angular brackets denote averaging with respect to the hydrometeor properties in the radar resolution volume, and $A_{hv} = \Delta A_h / \Delta A_v$ is the total round-trip differential attenuation in rain, which is a real number less than 1, and it can be approximated as:

$$10 \log_{10}(2 A_{hv}) = a\,\Phi_{DP}\;, \qquad (3)$$

The coefficient a (in dB/deg) depends on the radar wavelength, λ .

Using (1) and assuming the that the phase difference between horizontal and vertical transmitted components is β ,and the phase difference in the h and v receivers is γ, one can express the complex voltages measured for h and v polarizations in the STSR mode as:

$$V_h=[S_{hh}A_{hv}\exp\{j(\Phi_{DP}+\beta+\gamma)\}+S_{hv}A_{hv}{}^{1/2}\exp\{j(\Phi_{DP}/2+\gamma)\}]c$$
$$V_v=[S_{hv}A_{hv}{}^{1/2}\exp\{j(\Phi_{DP}/2+\beta)\} + S_{vv}]\,c\,, \qquad (4)$$

where c is a constant. For small canting angle dispersions, the terms containing S_{hv} can be neglected, and the estimated in the STSR mode ratio

$$\mathrm{DR} = \langle|V_h - V_v|^2\rangle / \langle|V_h + V_v|^2\rangle \qquad (5)$$

can be used as a proxy for C_{dr} if $\beta+\gamma=0$ (note that (5) would approximate (2) exactly if $\beta = -\gamma = -90^o$). Since Φ_{DP} estimates in this scheme are obtained as:

$$\langle\Phi_{DP}\rangle = \arg(\langle V_h V_v^*\rangle), \qquad (6)$$

$\beta+\gamma$ will represent an initial phase (i.e, a phase offset) from which the propagation differential phase will be accumulated as the range increases. This phase can be determined as an offset when measuring rain with a vertically pointed radar. For this measurement geometry, there is no propagation differential phase, and φ_{DP} estimates do not depend on range and they represent $\beta+\gamma$. By adjusting receiver cable lengths, $\beta+\gamma$ can be set to 0, as it was done during the Wallops field project with the ETL X-band polarimetric radar (Matrosov et al. 2002).

Unlike LDR, C_{dr} does not depend on hydrometeor canting in the polarization plane. Thus, in the absence of propagation effects, it can be used for estimates of hydrometeor axis ratios. Propagation effects in rain result in an increase of C_{dr} (for $\Phi_{DP} < 180^o$). When $\Phi_{DP} \approx 90^o$, the absolute values of the complex amplitude differences are approximately equal $|V_h - V_v| \approx |V_h + V_v|$, and $C_{dr} \approx 1$.

3. RESULTS OF MODELING

For $\beta+\gamma=0$, (5) provides a C_{dr} estimate. Results of modeling using (5) for λ=3.2 cm are shown in Fig.1, where values of CDR=10 $\log_{10}(C_{dr})$ are plotted as a function of Φ_{DP} . This modeling was performed using 3 different experimental drop size distributions which were measured by a Joss impact disdrometer during the Wallops experiment (Matrosov et al. 2002). The equilibrium drop shape was assumed. For this shape, drop aspect ratios are described as a function of equal-volume drop diameter:

$$r = 1.03 - b\,D \quad (b=0.6\ \text{cm}^{-1}). \tag{7}$$

For λ=3.2 cm, coefficient a in (3) is about 0.032 dB/deg.

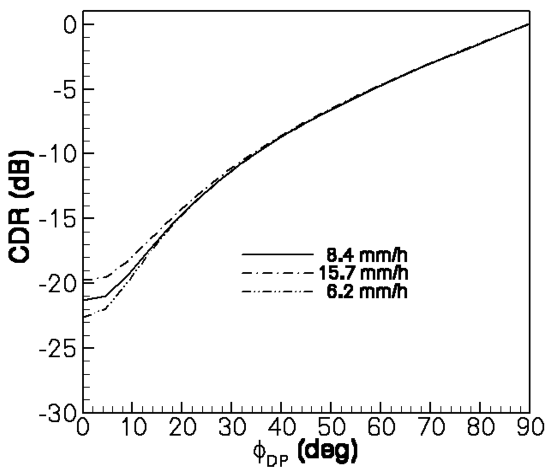

Fig.1. CDR as a function of Φ_{DP} at 3.2 cm

As it can be seen from Fig.1 propagation effects are significant and they need to be corrected in order to use C_{dr} . In linear units, this correction can be defined as

$$\Delta C_{dr} = [C_{dr}(\Phi_{DP}) - C_{dr}(\Phi_{DP}=0)]*100\% . \tag{8}$$

With increasing Φ_{DP}, this correction obviously will be progressively less accurate. Figure 2 shows ΔC_{dr} as a function of Φ_{DP} for the same experimental drop size distributions (DSDs) which were used in Fig.1. It can be seen that there is some variability due to DSD. It will degrade the accuracy of the correction. An average correction ΔC_{dr} can be approximated as a function of φ_{DP}:

$$\Delta C_{dr} = 0.00246\ \Phi_{DP}^{\ 2.33}. \tag{9}$$

As soon as propagation effects are corrected, C_{dr} can be used to estimate hydrometer shapes. Since C_{dr} does not depend on hydrometer canting in the polarization plane, it could be preferable to LDR which strongly depends on canting. Figure 3 shows a scatter plot of CDR in the absence of propagation effects as a function of median drop size D_o. Experimental Wallops DSDs were used here for modeling.

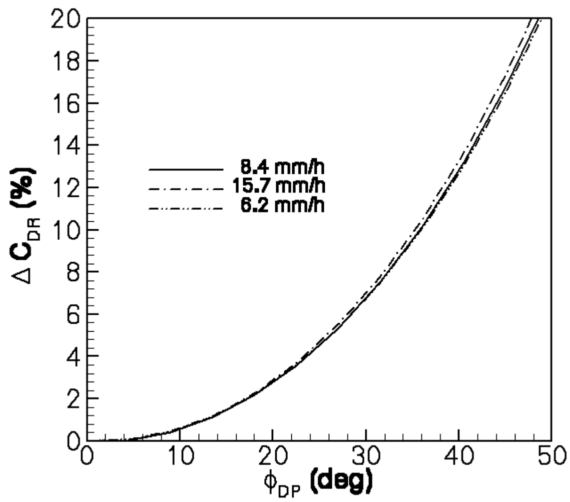

Fig.2. Δ C_{dr} correction as a function of Φ_{DP} at 3.2 cm

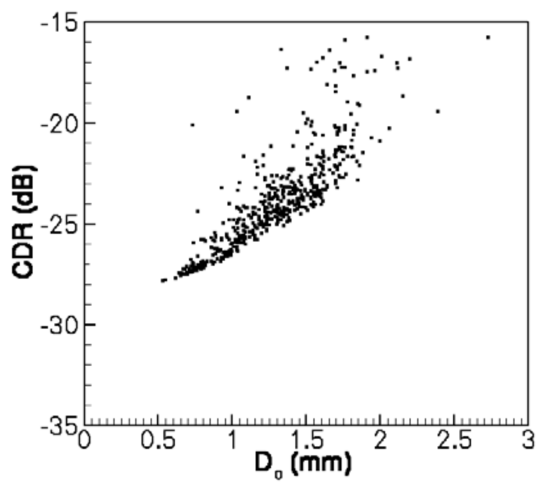

Fig.3. CDR(Φ_{DP} =0) *as a function of D_0 at 3.2 cm*

It was assumed in modeling that drop aspect ratios are given by (7) and the system polarization isolation is -28 dB (in power terms), which defined the minimal value of CDR in Fig.3. It can be seen that, except for some non-linearity at smaller median sizes which is caused by the polarzation leakage, the relation between CDR and D_0 is approximately linear:

$$\text{CDR(dB)} \approx 6\ D_0\ (\text{mm}) - 31.6 \tag{10}$$

How effectively propagation effects in rain can be accounted for in practice to make reasonable estimates of CDR(Φ_{DP}=0) remains to be seen. One anticipated practical difficulty is that for rather substantial values of Φ_{DP} these estimates will be sought as a small difference of two rather larger values (i.e., measured C_{dr} and Δ C_{dr}), so the quality of the propagation effects removal will degrade as Φ_{DP} increases.

4.EXPERIMENTAL EXAMPLES

Figure 4 shows an example of CDR estimates in an ice cloud. The data depict the elevation angle dependence of CDR at a constant height of 5.5 km. For comparisons, Z_{DR} data are also shown. The measurements were taken by the NOAA/ETL X-band radar. It was established that for this radar the sum $\beta+\gamma$ is about 0.06 radian . A correction for this was made by multiplying V_h voltages by the coefficient exp(-*j**0.06). No significant accumulation of differential phase was measured in this cloud; hence, no correction for propagation effects was attempted.

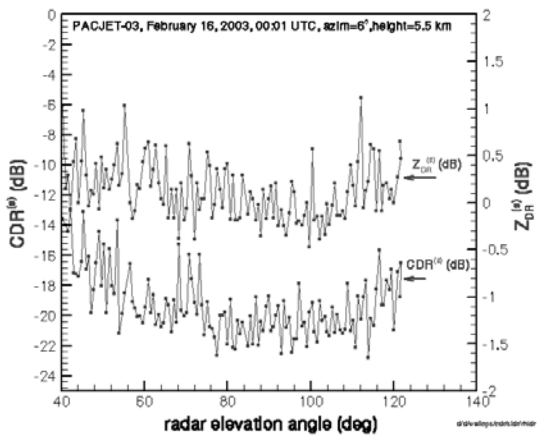

Fig.4. CDR estimates in a ice cloud made of dendrites

The CDR as a function of the radar elevation angle from Fig.4 exhibits a typical pattern associated with rimed dendrites. Lower in a cloud, heavy aggregation takes place. Particles become irregular in shape and do not exhibit any distinct polarization signatures. The corresponding CDR estimates at a 3.5 km level inside the cloud are shown in Fig. 5.

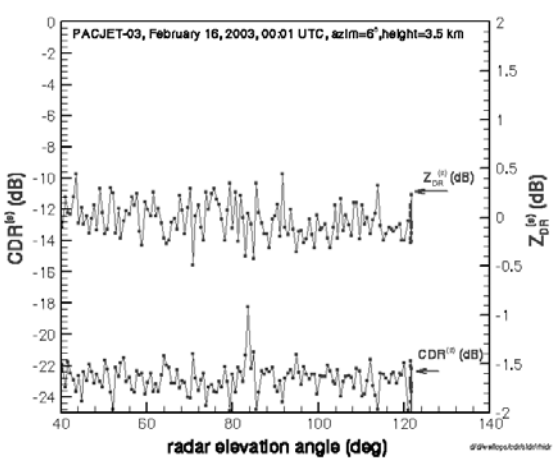

Fig.5. CDR in a ice cloud made of irregular snowflakes

Figure 6 shows estimates of CDR and Φ_{DP} along the radar beam as functions of range in light rain. The solid line in this figure shows estimates of CDR as a function of Φ_{DP} which is plotted along the upper X-axis. Since both CDR and Φ_{DP} estimates are noisy, CDR=f(φ_{DP}) is approximated by a polynomial curve. The CDR increase as a function of Φ_{DP} is in agreement with the theoretical results in Fig. 1.

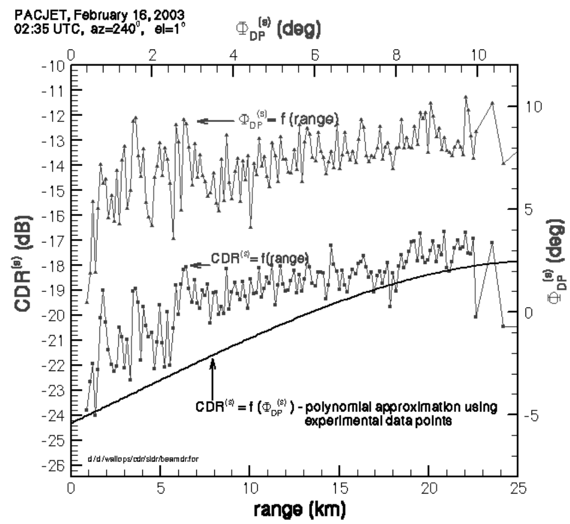

Fig.6. CDR estimates in light rain

5. CONCLUSIONS

The suggested approach to estimate CDR from STSR polarimetric measurements can be useful for ice hydrometeor identification studies. CDR can be used for estimating shapes of ice particles and discriminating them from super-cooled water drops (Matrosov et al. 2001). Φ_{DP} in nonprecipitating ice clouds are not expected to be large, especially when viewed at higher elevation angles.

An important advantage of the considered scheme of estimating CDR is that it does not require high sensitivity since all signals are measured as “strong” channel echoes. Radars using his scheme can be about 3 orders of magnitude less sensitive compared to the ones that must measure “strong” and “weak” channel echoes to get estimates of depolarization. Hence, a moderately sensitive X-band radar could make similar CDR-based cloud classifications that heretofore have required using high-sensitivity mm-wavelength radars (Matrosov et al. 2001).

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