Towards a CDR-based Rain Rate Estimation Algorithm for Zenith-pointing Cloud Radars at Ka band.

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1. Abstract

We focus on measurements of circular depolarization ratio (CDR) in rain with the Atmospheric Radiation Measurement (ARM) Millimeter wave cloud radar (MMCR) in search for signatures due to non-axisymmetric oscillation of raindrops. If the depolarization ratio is obtained from the so-called polarimetric mode (5 main channel and 6 weak channel), CDR enhancements in the lower part of the troposphere are well visible, and are caused by main channel saturation. If the depolarization ratio is obtained from the precipitation mode (4 main channel and 6 weak channel), then a correlation between CDR and max drop diameter and between CDR and rain rate can be observed. Potentially, the sensitivity of mm-wave radars to depolarization from oscillating raindrops may be used for quantitative estimation, provided the cross-polar isolation of the antenna is improved to better than -30 dB and the receiver architecture is designed to provide truly dual-pol measurements (simultaneous reception of co-pol and cross-pol channels).

2. Introduction

The ARM-MMCR radar operated (until 2011) at Ka band (35 GHz) and transmitted circular polarization, providing measurements of reflectivity at circular polarization (Z_C) and Circular Depolarization Ratio (CDR).

$$Z_C \equiv \langle |s_{lr}|^2 \rangle$$

$$\mathrm{CDR} \equiv \frac{\langle |s_{rr}|^2 \rangle}{\langle |s_{lr}|^2 \rangle}$$

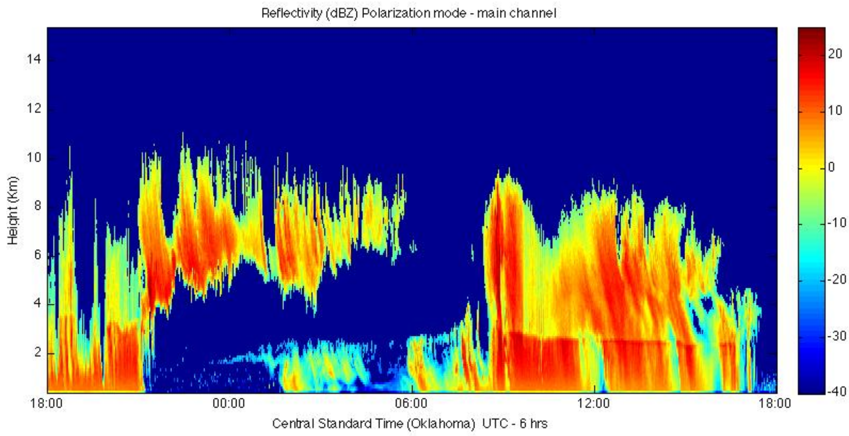
The MMCR is essentially a single channel system, and measures the circular depolarization ratio by measuring first cross-polar (mode 5) and subsequently copolar (mode 6) power. Neither the cross-polar correlation coefficient at circular polarization (ORTT) nor the degree of polarization at circular transmit (p_C) can be measured.

$$ORTT \equiv \frac{\langle s_{rr} s_{lr}^* \rangle}{\sqrt{\langle |s_{rr}|^2 \rangle \langle |s_{lr}|^2 \rangle}}$$

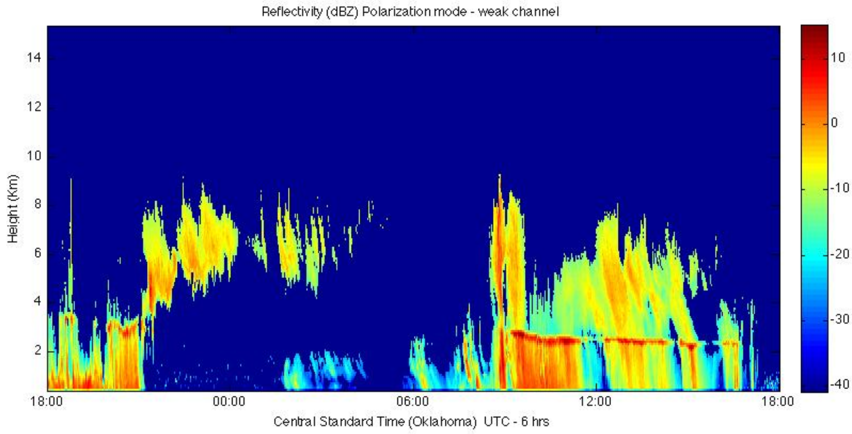
$$p_C = \sqrt{1 - \frac{4\left[\langle |s_{rr}|^2 \rangle \langle |s_{lr}|^2 \rangle - \left|\langle s_{rr} s_{lr}^* \rangle\right|^2\right]}{[\langle |s_{rr}|^2 \rangle + \langle |s_{lr}|^2 \rangle]^2}}$$

Use of mm-wave radars for the study of rain microphysics is motivated by the fact that shorter wavelengths are more sensitive to depolarization from oscillating raindrops and break-up than longer wavelengths [1]. In a zenith pointing geometry, the observable raindrop oscillations come from non-axisymmetric modes [2]. In the present paper we set out to investigate the dynamic range of CDR in response to these types of raindrop oscillations. A significant difficulty of our study is the limited dynamic range of the MMCR. With cloud radars operating at millimeter wavelengths, receiver saturation may occur for light rain (~ 10-20 dBZ), with a consequent degradation of the CDR retrieval capabilities of the system. With the standard CDR provided by the MMCR (mode 6 to mode 5 ratio), saturation of the main (cross-polar) channel induces a CDR enhancement visible at close ranges from the antenna: this happens because while the main channel saturates to a constant power value, the weak channel is still linearly responsive to the backscattered radiation. In order to retrieve depolarization signatures from rain, we then resort to employ mode 4 as the main channel (precipitation mode) instead of mode 5. In mode 4, an attenuator is switched on at the radar front-end yielding a nominal attenuation of 22-23 dB. This additional attenuation is then corrected for in the digital signal processor. Besides observing non-axisymmetric oscillations of raindrops, our analysis permits to calibrate the attenuation applied at the radar front end. The results indicate that the attenuator actually dampens the signal 5.1 dBZ more than what is actually accounted for in the processor.

3. CDR enhancement due to main channel saturation



A



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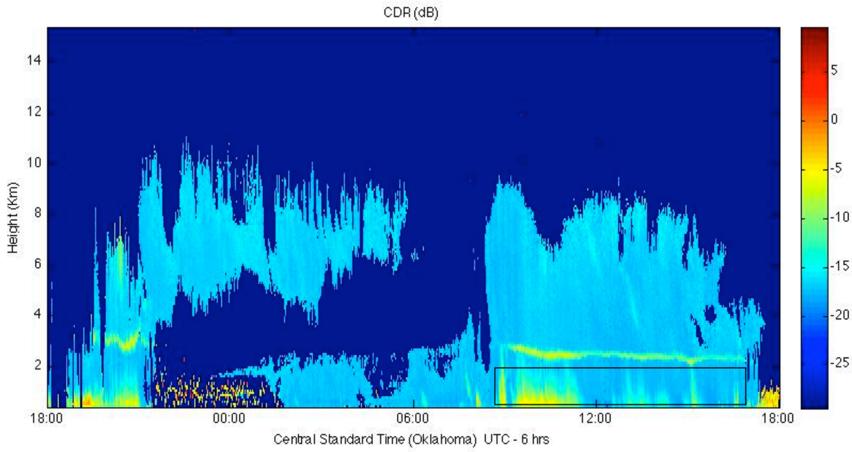


C

Fig1 A: main channel Reflectivity (dBZ); B: weak channel reflectivity (dBZ); C Circular Depolarization Ratio (dB). Note the enhanced CDR values at close ranges in the black rectangle in C.

We consider a stratiform precipitation event from April 29th 2006 observed with the MMCR from the SGP ARM site, close to Lamont, OK. The time-height diagram features a distinct bright band between 2 and 3 km height, with raindrops in the region below it. Of interest are the CDR enhancements visible in the lower part of the troposphere. The following scatterplots are made for the area comprised in the black rectangle in the CDR time-height diagram shown above. In Fig. 2A is the scatterplot of main channel reflectivity versus weak channel reflectivity. The hockey stick shape indicates saturation of the main channel for reflectivity values larger than approximately 10 dBZ. If unsaturated reflectivity from the precipitation mode is used (mode 4 – Fig. 2B) the hockey stick shape disappears, and leaves place to a linear relation between copolar and cross-polar reflectivity. The linear relation is expected for quasi-spherical scatterers because of antenna cross-channel coupling [6]. The intercept in Fig. 2A and 2B is the difference between copol and cross-pol power: between mode 5 and mode 6 (A) and between mode 4 and mode 6 (B) respectively. The difference between the intercept in Fig. 2A and 2B is due to the uncorrected contribution from the attenuator in the antenna front end, approximately 5 dBZ in this case.

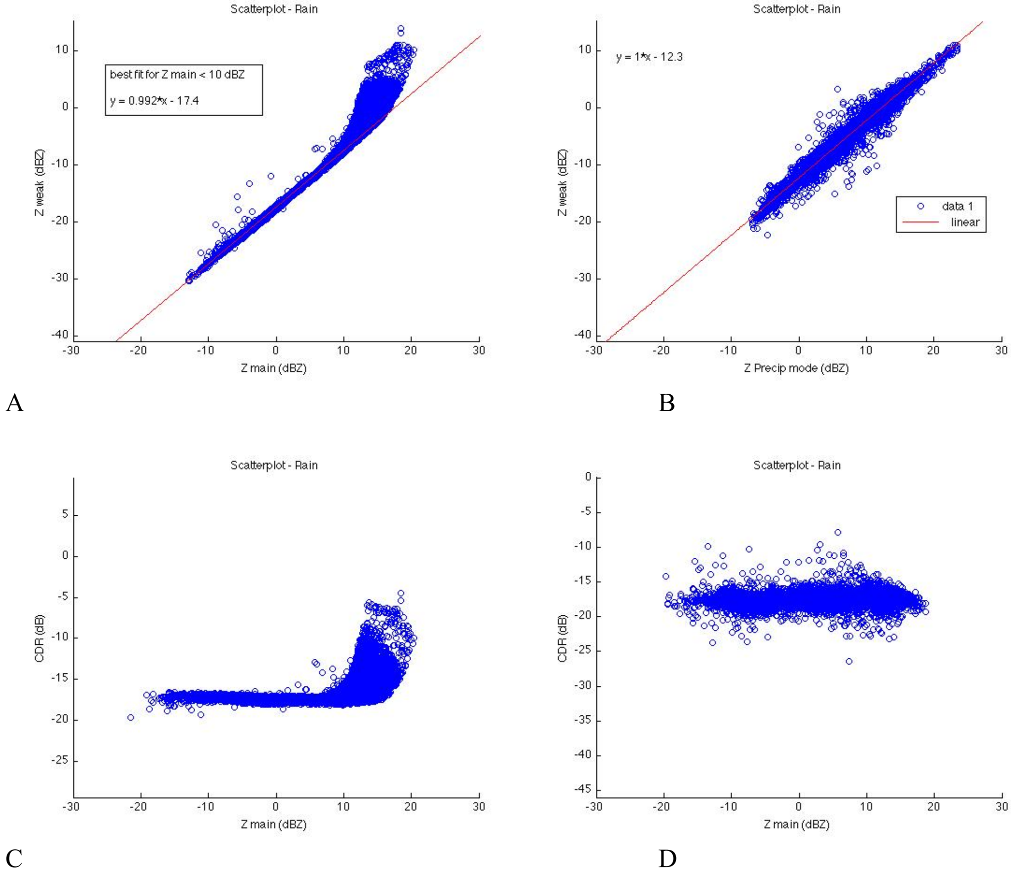


Fig. 2 Scatterplots for the black rectangle in Fig. 1C. On the left (A and C), mode 5 and 6 are used. Here, main channel saturation occurs. On the right (B and D) mode 4 and 6 are used. The relation between copolar and cross-polar power is approximately linear for this light precipitation event, due to antenna coupling and quasi-spherical scatterers.

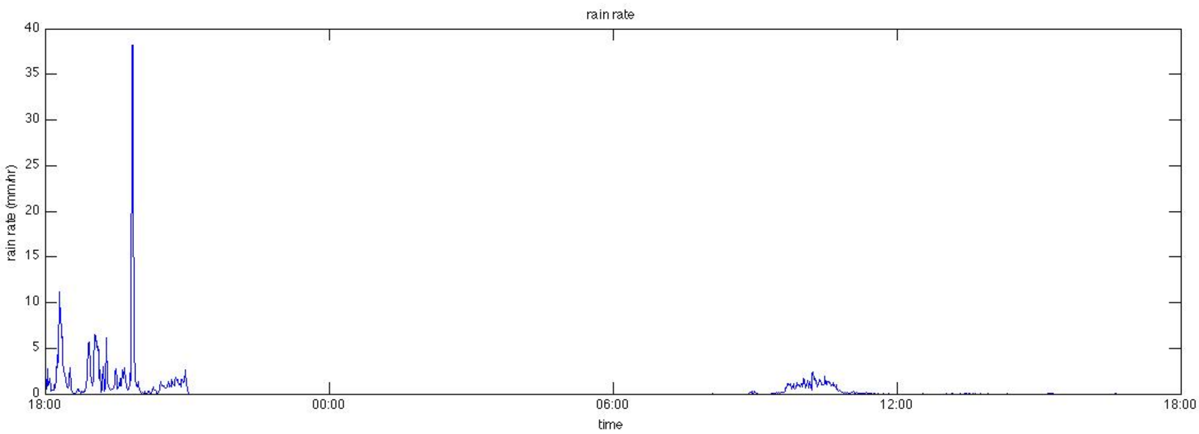


Fig. 3 ARM-SGP Impact Disdrometer measurements of rain rate for April 29th 2006.

The radar measurements are compared with results from the impact disdrometer (Joss-Waldvogel disdrometer) on the ground. The products we consider are the rain rate (mm/hr) and the maximum drop diameter (mm). If the main channel saturation problem can be overcome by using the precipitation mode (mode 4), measurements of intrinsic depolarization ratio should correlate with maximum drop diameter and/or rain rate. Such measurement relies on the fact that the bigger the raindrops, the greater the oscillation amplitude of its non-axisymmetric modes [2]. This measurement approach taps into a microphysical feature that has been poorly exploited in the past [1].

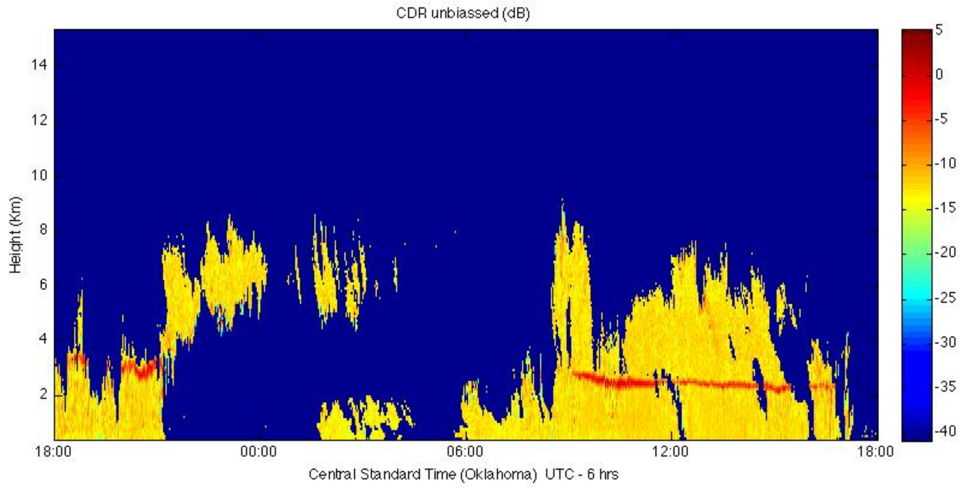
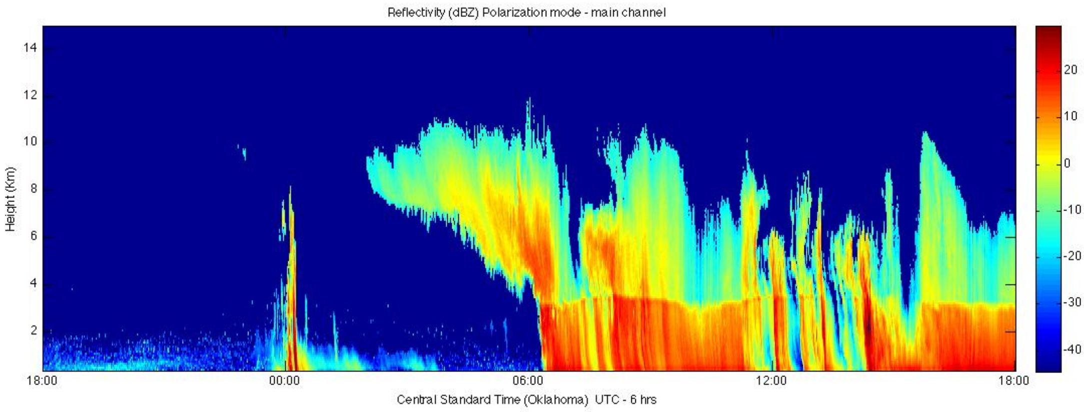


Fig. 4 Unbiassed CDR time-height diagram obtained from mode 4 (precip mode) and mode 6 (weak channel).

4. CDR – Correlation with rain rate and maximum drop diameter.

We now consider the event of May 7th 2008, observed with the MMCR at the SGP ARM site. Even if the MMCR has poor cross-polar antenna isolation (minimum CDR is approximately -18 dB), a correlation between depolarization ratio and rain rate, and between depolarization ratio and maximum drop size is observable when mode 4 (precipitation mode) is used instead of mode 5.



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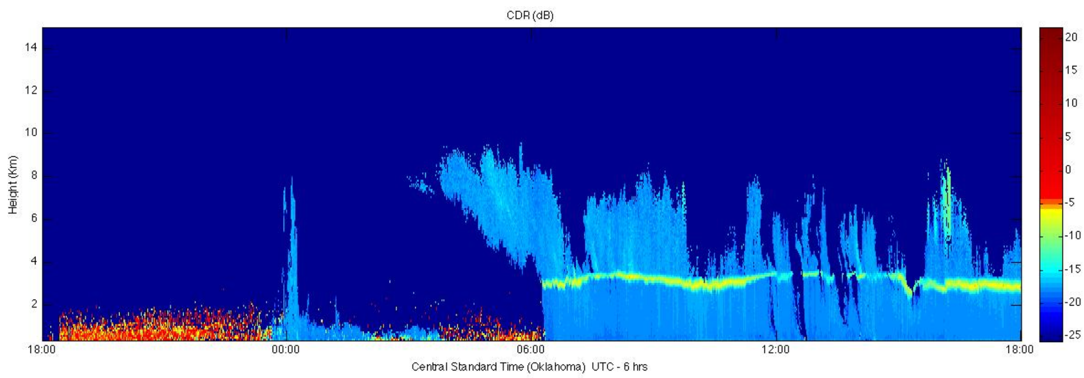
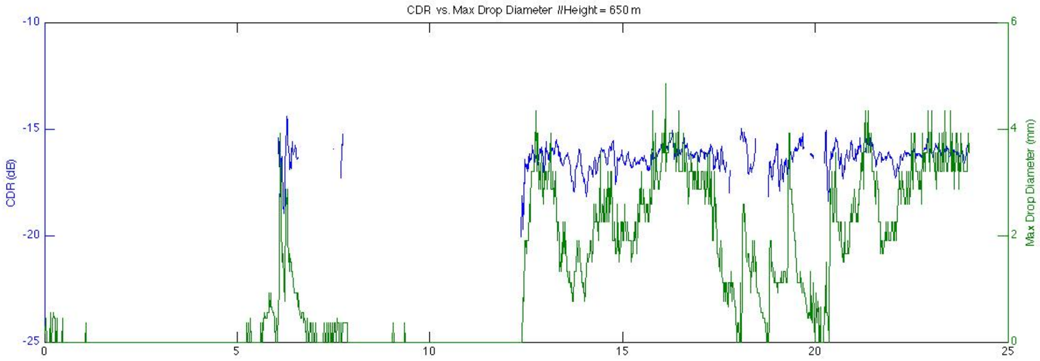
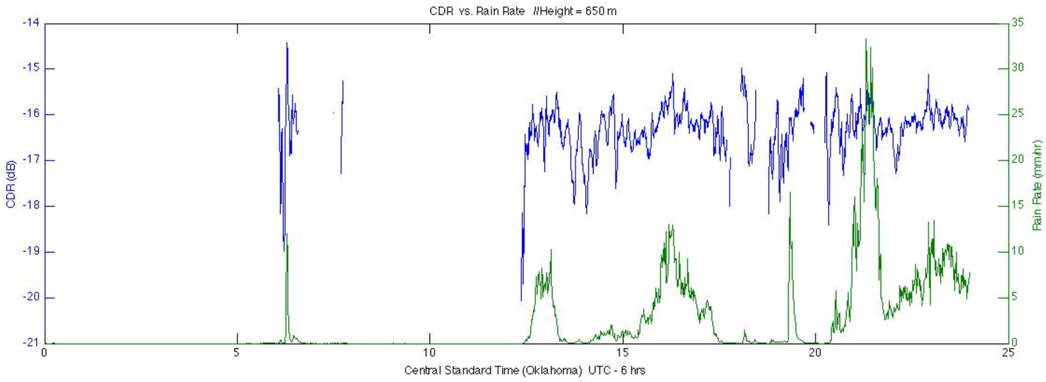


B

Fig. 5 A: Reflectivity (dBZ); B Circular Depolarization Ratio (dB).



A



B

Fig. 6 In blue is the Circular Depolarization Ratio (CDR in dB) in green is A: maximum drop diameter (in mm) and B: the rain-rate (mm/hr).

The graphs in Fig. 6 show the Circular Depolarization Ratio (CDR in dB, in blue) against the maximum drop diameter (A, in mm) and the rain-rate (B, in mm/hr). Disdrometer data are obtained from the impact disdrometer at the SGP ARM site (datastream: sgpdisdrometer). A visual correlation between the plots can be observed and it is demonstrated that it is possible to capture drop oscillations with depolarization ratio measurements. In particular, the maximum diameter drop time series appears to correlate better with CDR than the rain rate time series. However, CDR lacks the desirable dynamic range to attempt quantitative estimation. A significant improvement may come if the minimum measurable CDR (dictated by antenna cross-polar isolation) is lowered to about -30 dB. This can be achieved with a dual-pol receiver (simultaneous reception of copolar and cross-polar channels) and dedicated signal processing.

5. CONCLUSIONS

We provided evidence of correlation between depolarization ratio (CDR) and maximum drop diameter and between depolarization ratio and rain-rate. We attribute these enhancements to non-axisymmetric oscillations of raindrops as described in [2]. The observations are generally complicated by the saturation of the radar main channel, occurring in correspondence of the target of interest (rain, with Z > 10 – 20 dBZ). This circumstance forces to use acquisition modes separated in time (mode 4 and mode 6) that may blur the correlation between the signals [7]. Obviously, the correlation between CDR and rain (either rain rate or maximum drop diameter) disappears in presence of insects/atmospheric plankton. Use of a dual-pol receiver may solve the problem of simultaneous acquisitions and at the same time it helps eliminate the bias induced by antenna cross-channel coupling [6].

Ultimately, the relation between copolar and cross-polar reflectivity is approximately linear in rain. This is due to antenna cross-channel coupling and by the quasi-spherical shape of raindrops. This circumstance is helpful since it permits to calibrate the attenuator switched on in the precipitation mode: comparison of main channel reflectivity of mode 4 and mode 5 with the same weak channel reflectivity of mode 6 yields the mismatch between the actual attenuation at the antenna front-end and the correction applied in the digital signal processor. In our case, the measured mismatch was about 5 dBZ.

References

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