Zenith/nadir-pointing Cloud Radars: Linear or Circular Polarization ?

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Introduction

- In zenith/nadir pointing mm-wave cloud radars, dual-polarization was originally introduced for enhanced detection of insect clutter. Insects may have random headings, or may be aligned in the same flight direction. However, meteorological scatterers (ice crystals, cloud drops, rain drops) always display azimuth symmetry at zenith/nadir.
- Here, we consider scatterers with azimuth symmetry, and explore the effects of transmit polarization (either linear or circular) on the retrieved polarimetric variables: reflectivity, depolarization ratio, cross-polar coherence and degree of polarization.
- It is found that, for scatterers with azimuth symmetry, reflectivity is maximized at linear polarization tx (probably preferable for single-pol systems) whereas the depolarization ratio dynamic range is maximized at circular polarization tx (preferable for dual-pol systems).

Simulations of Scatterers with Azimuth Symmetry

- We use Mishchenko T-matrix code to evaluate the Kennaugh matrix of scatterers with azimuth symmetry.

1. Non axisymmetric oscillations of raindrops.

At Ka band, for a cloud of monodispersed randomly oriented spheroids with D = 2 mm – a/b = 0.83 we obtain the following Kennaugh matrix:

$$K_{rain\_2}=\begin{bmatrix}1.6533 & 0 & 0 & 0\\ 0 & 1.6338 & 0 & 0\\ 0 & 0 & -1.6338 & 0\\ 0 & 0 & 0 & -1.6144\end{bmatrix}$$

Yielding CDR = -19.23 dB and LDR = -22.27 dB.

At Ka band, for a cloud of monodispersed randomly oriented spheroids D = 6 mm – a/b = 0.6 we obtain the following Kennaugh matrix:

$$K_{rain\_6}=\begin{bmatrix}0.4825 & 0 & 0 & 0\\ 0 & 0.4520 & 0 & 0\\ 0 & 0 & -0.4520 & 0\\ 0 & 0 & 0 & -0.4214\end{bmatrix}$$

yielding CDR = -11.71 dB and LDR = -14.86 dB.

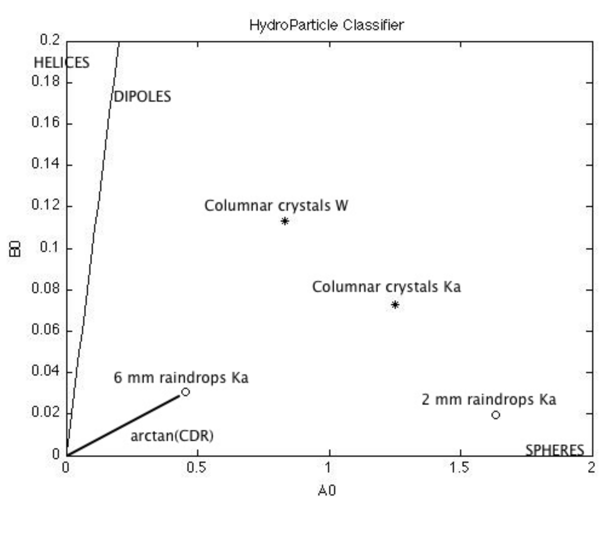
2. Columnar Ice Crystals

At W band, for a cloud of randomly oriented columnar crystals with D = 0.4 mm and L = 2 mm we obtain:

$$K_{columns\_W}=\begin{bmatrix}0.9444 & 0 & 0 & 0\\ 0 & 0.8314 & 0 & 0\\ 0 & 0 & -0.8314 & 0\\ 0 & 0 & 0 & -0.7184\end{bmatrix}$$

yielding CDR = -8.67 dB and LDR = -12 dB.
For the same target, at Ka band the simulation yields CDR = -12.3 dB and LDR = -15.4 dB.

Scatterers with azimuth symmetry can be fully described by two degrees of freedom, like reflectivity and depolarization ratio.



Note how the perceived shape of scatterers is dependent on wavelength. The same crystals are perceived with different shapes at different frequencies.

The simulations for oscillating raindrops are reported in the A_0 – B_0 plane.
At mm wavelengths, oscillating drops produce larger depolarization than what would be expected at cm wavelengths.

Polarimetric Theory for Scatterers with Azimuth Symmetry

Apart from insects, that may have a preferred heading since they elongated bodies may fly in the same direction, meteorological scatterers (apart from electrified crystals) generally display azimuth symmetry at zenith/nadir viewing. Here, we reprise and expand the theoretical results in [3] to understand the impact of transmit polarization on the behavior of reflectivity and depolarization ratio under the assumption of azimuth symmetry.

At circular polarization, the covariance matrix for scatterers with az symmetry is:

$$\Sigma_{BSA}^{C}=\begin{bmatrix}\langle|s_{RR}|^2\rangle & 0 & 0\\ 0 & 2\langle|s_{LR}|^2\rangle & 0\\ 0 & 0 & \langle|s_{RR}|^2\rangle\end{bmatrix}$$

At linear polarization, the covariance matrix for scatterers with az symmetry is:

$$\Sigma_{BSA}^{L}=\begin{bmatrix}\langle|s_{HH}|^2\rangle & 0 & \langle s_{HH}s_{VV}^{*}\rangle\\ 0 & 2\langle|s_{VH}|^2\rangle & 0\\ \langle s_{HH}^{*}s_{VV}\rangle & 0 & \langle|s_{HH}|^2\rangle\end{bmatrix}$$

The Kennaugh matrix corresponding to az symmetry is

$$K_{az}=\begin{bmatrix}A_0+B_0 & 0 & 0 & 0\\ 0 & A_0 & 0 & 0\\ 0 & 0 & A_0 & 0\\ 0 & 0 & 0 & -A_0+B_0\end{bmatrix}$$

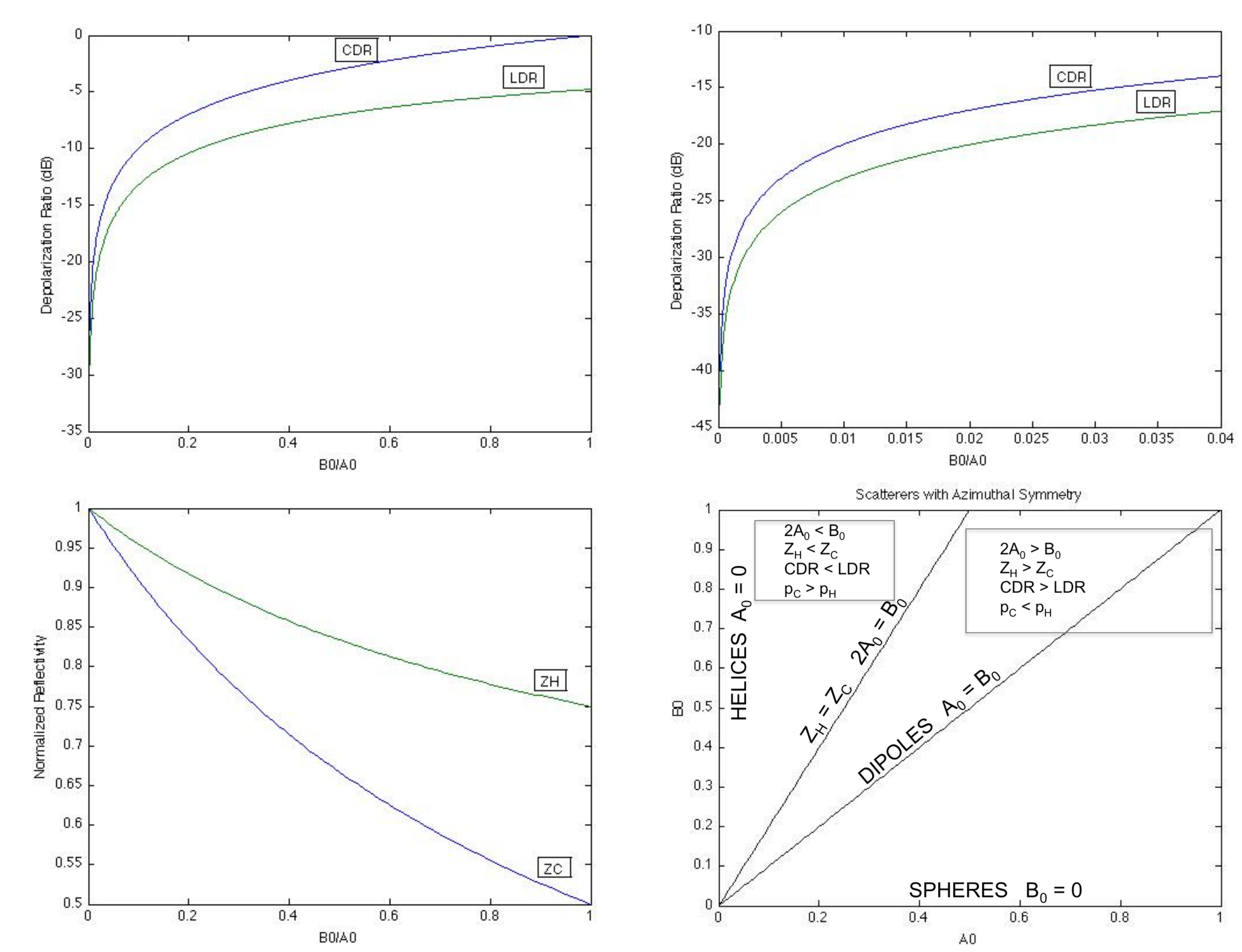
Since the trace is invariant under SU(3) transformations, we obtain

$$Z_H[1+LDR]=Z_C[1+CDR]=A_0+B_0$$

Further, for the depolarization ratios LDR and CDR we obtain the following:

$$LDR=\frac{B_0}{2A_0+B_0}$$

$$CDR=\frac{B_0}{A_0}$$

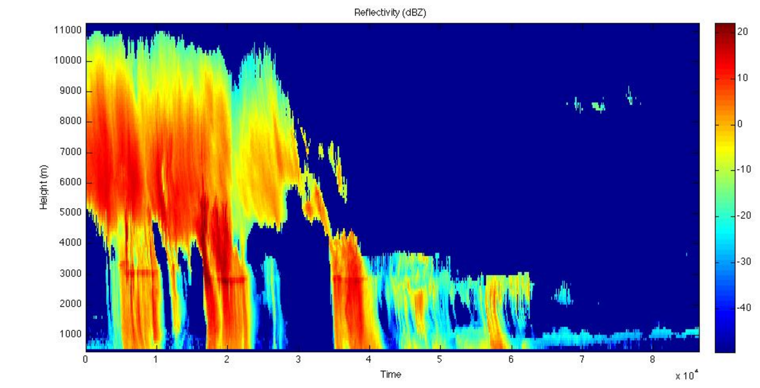


CONCLUSIONS
For scatterers with azimuth symmetry
LDR < CDR and $Z_H > Z_C$

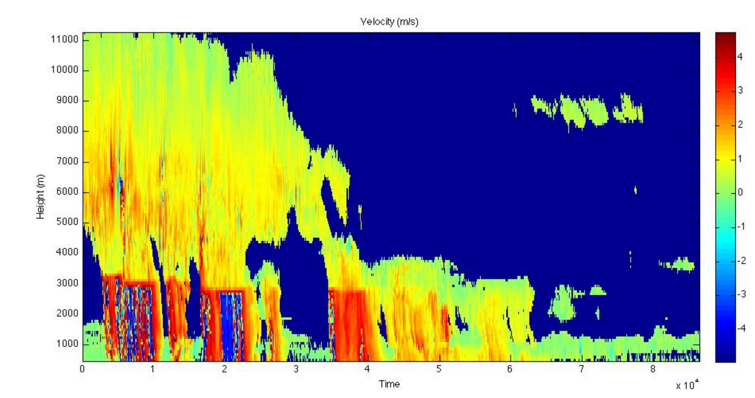
For zenith/nadir pointing cloud radars (azimuth symmetry)

- linear polarization might be preferable for single-pol systems (reflectivity is maximized).
- In the extreme case of a cloud of dipoles $Z_H > Z_C$ by 1.76 dBZ
- Circular polarization might be preferable for dual-pol systems (the depolarization ratio dynamic range is maximized).
- In the extreme case of a cloud of dipoles, CDR > LDR by 4.77 dB

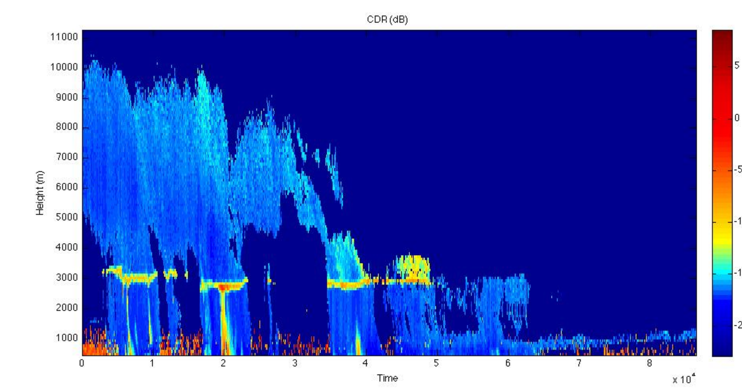
Why polarimetry for zenith/nadir Pointing Cloud Radars ? MMCR – Ka band – Circular Pol Tx



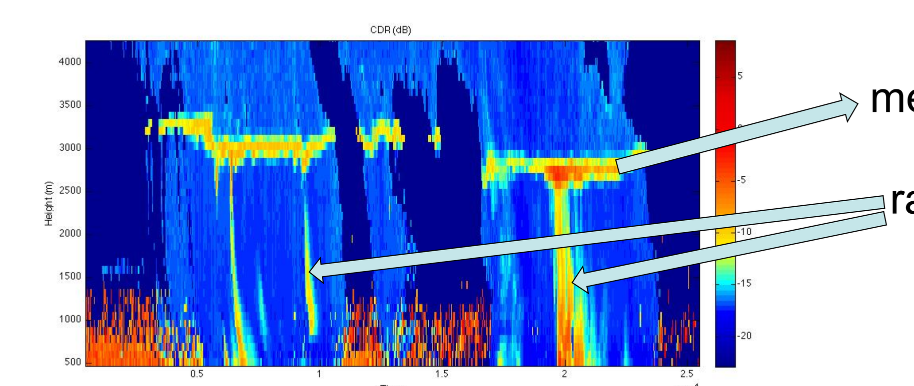
Reflectivity (dBZ)
Note how the melting band is not well detected.



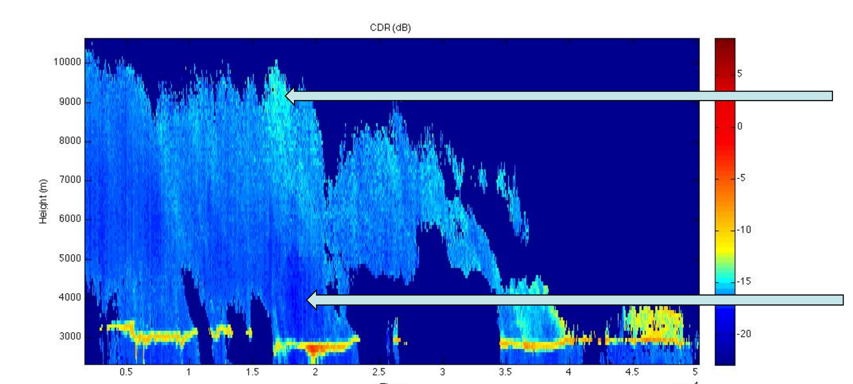
Velocity (m/s)
Vertical velocity detects the presence of rain, yet, it does not detect the melting band itself.



CDR (dB) detects insects and melting band, rain-streaks due to oscillating raindrops and break-up, and ice crystal habit.



melting band
rain-streaks



Pristine crystals
Rimed/aggregated crystals

The capabilities of dual-polarization systems extend far beyond the detection of insect clutter:

- High-resolution imaging of the melting band: thickness, up and down notches…
- Identification of rainfall streaks due to oscillating raindrops and break-up processes
- Ice crystal habit identification: pristine vs. aggregated/rimed

Research to improve the antenna cross-polar isolation of mm wave radars is highly needed in order to extend the usable dynamic range. In the case of MMCR, minimum measurable CDR is around -18 dB.

References

1. M. Galletti, D. Huang, P. Kollias “Zenith/nadir-pointing Cloud Radars: Linear or Circular Polarization ?” submitted to the TGRS
2. Jameson, A. R., S.L. Durden, 1996, “A possible origin of Linear Depolarization observed at vertical incidence in rain” *J. Appl. Meteor.*
3. Tang and Aydin, “Scattering from ice crystals at 94 and 220 GHZ millimeter wave frequencies” TGRS, 1995.