Towards a CDR-based rain rate estimation algorithm for zenith-pointing cloud radars at Ka band

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SUMMARY

• Non-axysymmetric drop oscillations and their impact on Depolarization ratio $\rightarrow$ CDR and LDR

• T-matrix simulations of oblate spheroids

• MMCR observations of rain

• Conclusions
The physics behind the signature: Non-axisymmetric oscillations of raindrops
Non-axisymmetric oscillations of raindrops do cause depolarization even at zenith/nadir

\[ D_{\text{raindrop}} = 1.8 \text{ mm} \]


At zenith/nadir viewing, raindrops exhibit azimuth symmetry → 2 degrees of freedom usually encapsulated in Reflectivity and Depolarization Ratio

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

\[
\Sigma^L_{BSA} = \begin{bmatrix}
\langle |s_{HH}|^2 \rangle & 0 & \langle s_{HH} s_{*VV} \rangle \\
0 & 2\langle |s_{VH}|^2 \rangle & 0 \\
\langle s_{*HH} s_{VV} \rangle & 0 & \langle |s_{HH}|^2 \rangle
\end{bmatrix}
\]

\[
\rho_{hv} = 1 - 2LDR
\]

For scatterers with azimuth symmetry, CDR has a larger dynamic range wrt LDR → Circular polarization may be a better option.

Spheres

Randomly oriented dipoles

Depolarization Ratio (dB)

\[0 \quad -10 \quad -20 \quad -30 \quad -35\]

\[B_0/A_0 \quad 0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1\]
T-matrix simulations of spheroids

We used Mishchenko T-matrix code to compute the Muller matrix of monodispersed randomly oriented spheroids (prolate or oblate yield similar results)

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

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

CDR = -19.23 dB
LDR = -22.27 dB

CDR = -11.71 dB
LDR = -14.86 dB

Millimeter waves are very sensitive to depolarization from drop oscillations !!!

If the antenna has good isolation (e.g. -35 dB) the dynamic range is significant, and quantitative retrieval could be attempted!
MMCR observations of rain
MMCR at SGP (Ka band) operates in a number of different modes:

1. Boundary Layer mode
2. Cirrus mode
3. General mode
4. Precipitation mode

An attenuator is switched on at the radar front-end to prevent saturation in rain.

1. Main channel
2. Weak channel

These channels are used to compute CDR. Mode 5 is very similar to mode 3.
Case 1: April 29\textsuperscript{th} 2006
The CDR flares we just saw are caused by saturation, not by raindrop oscillations!!

Reflectivity (mode 5) vs. Reflectivity (mode 6)

The hockey-stick shape disappears when the precipitation mode is used:

The flares in Depolarization Ratio are due to main channel saturation!

Reflectivity (mode 4) vs. Reflectivity (mode 6)

The difference in the intercept in the two graphs above permits to compute the calibration mismatch of the attenuator at the front-end: approximately 5 dBZ
Light to moderate rain may saturate the main channel: CDR shows saturation flares -
SATURATION FLARES

- Cloud radars are designed to detect clouds, generally, their dynamic range is between -60 dBZ and +20 dBZ

- In light (20 dBZ) and moderate (30 dBZ) rain, the main channel saturates....

- This induces spurious DR (Depolarization Ratio) flares at close ranges from the antenna.
Rain with $Z > 20$ dBZ

Because of antenna coupling, $Z_{\text{cx}}$ is proportional to $Z_{\text{co}}$

$Z_{\text{co}} - Z_{\text{cx}} \sim 20$ dBZ

Difference between main and weak channel is approx. 20 dB

Main channel is saturated, weak channel still accepts incoming power

$\text{DR} = \frac{Z_{\text{weak}}}{Z_{\text{main}}} \text{ soars} !!!$
Depolarization Ratio signatures of non-axisymmetric drop oscillations

Case 2: May 7\textsuperscript{th} 2008
Case 1: April 29\textsuperscript{th} 2006
If the main channel is not saturated, CDR correlates with the rain rate (below) and the maximum drop diameter (above). Height is 650 m.
CONCLUSIONS

• Saturation flares may appear in DR measurements in light/moderate rain

• If the precipitation mode is used in the computation of CDR, then a correlation between CDR and rain rate and CDR and maximum drop diameter can be observed.

• Scatterplots of main and weak channel reflectivity can be used to (fairly accurately) calibrate the attenuator in the radar front-end
FUTURE WORK

- Attempt quantitative precipitation estimation.

- Reconstruction of main channel reflectivity from weak channel reflectivity in the case of strong scatterers and quantify the uncertainty.
Thank You!
Questions?

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