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

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SUMMARY

- Non-axysimmetric drop oscillations and their impact on Depolarization ratio → CDR and LDR

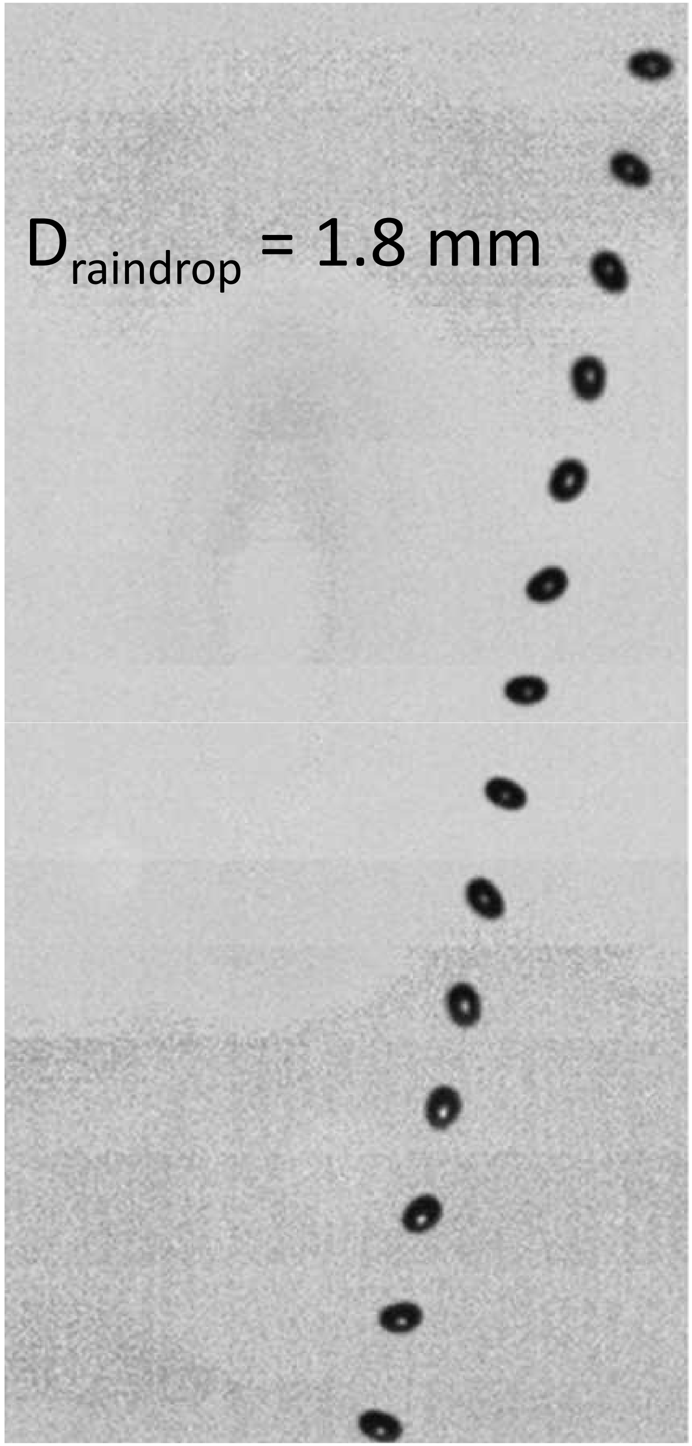
- T-matrix simulations of oblate spheroids

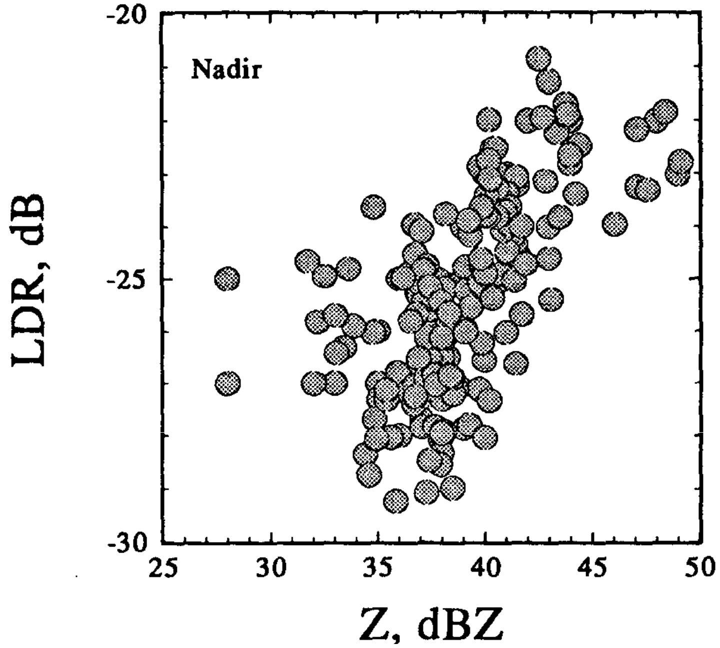
- MMCR observations of rain

- Conclusions

The physics behind the signature: Non-axisymmetric oscillations of raindrops

Non-axisymmetric oscillations of raindrops do cause depolarization even at zenith/nadir





Ku band
13.8 GHz at nadir

Jameson, A. R., S. L. Durden, 1996: A Possible Origin of Linear Depolarization Observed at Vertical Incidence in Rain. *J. Appl. Meteor.*, **35**, 271–277

Testik, F. Y., A. P. Barros, L. F. Bliven, 2006: Field Observations of Multimode Raindrop Oscillations by High-Speed Imaging. *J. Atmos. Sci.*, **63**, 2663–2668.

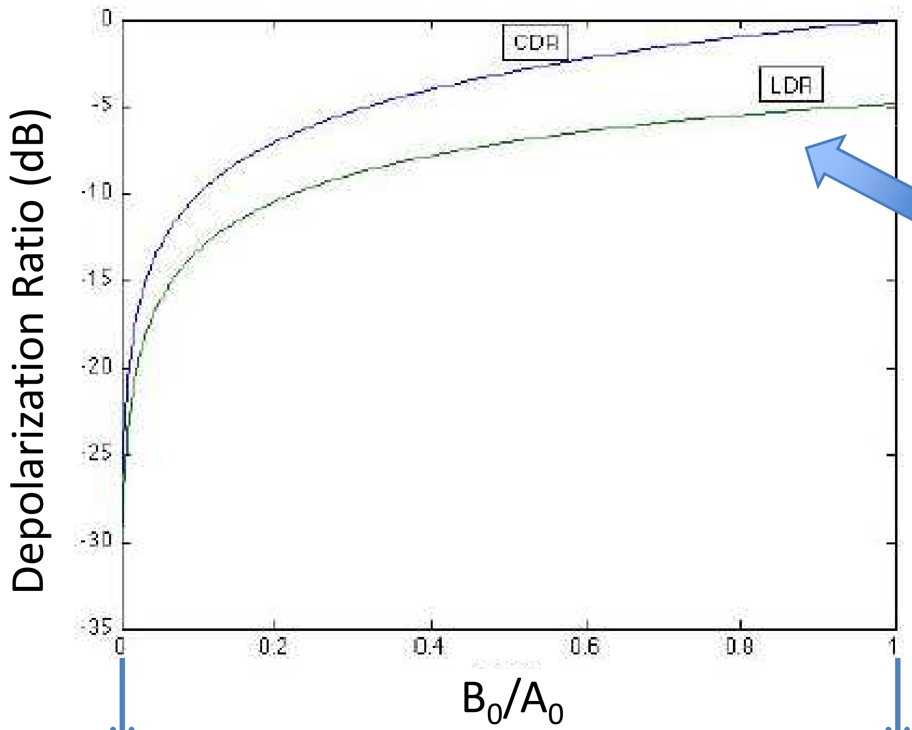
At zenith/nadir viewing, raindrops exhibit azimuth symmetry → 2 degrees of freedom usually encapsulated in Reflectivity and Depolarization Ratio

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

⟷

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

$$\rho_{hv} = 1 - 2LDR$$



Spheres

Randomly oriented dipoles

For scatterers with azimuth symmetry, CDR has a larger dynamic range wrt LDR →

Circular polarization may be a better option.

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)

D = 2 mm a/b = 0.83

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

CDR = -19.23 dB
LDR = -22.27 dB

D = 6 mm a/b = 0.6

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

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:

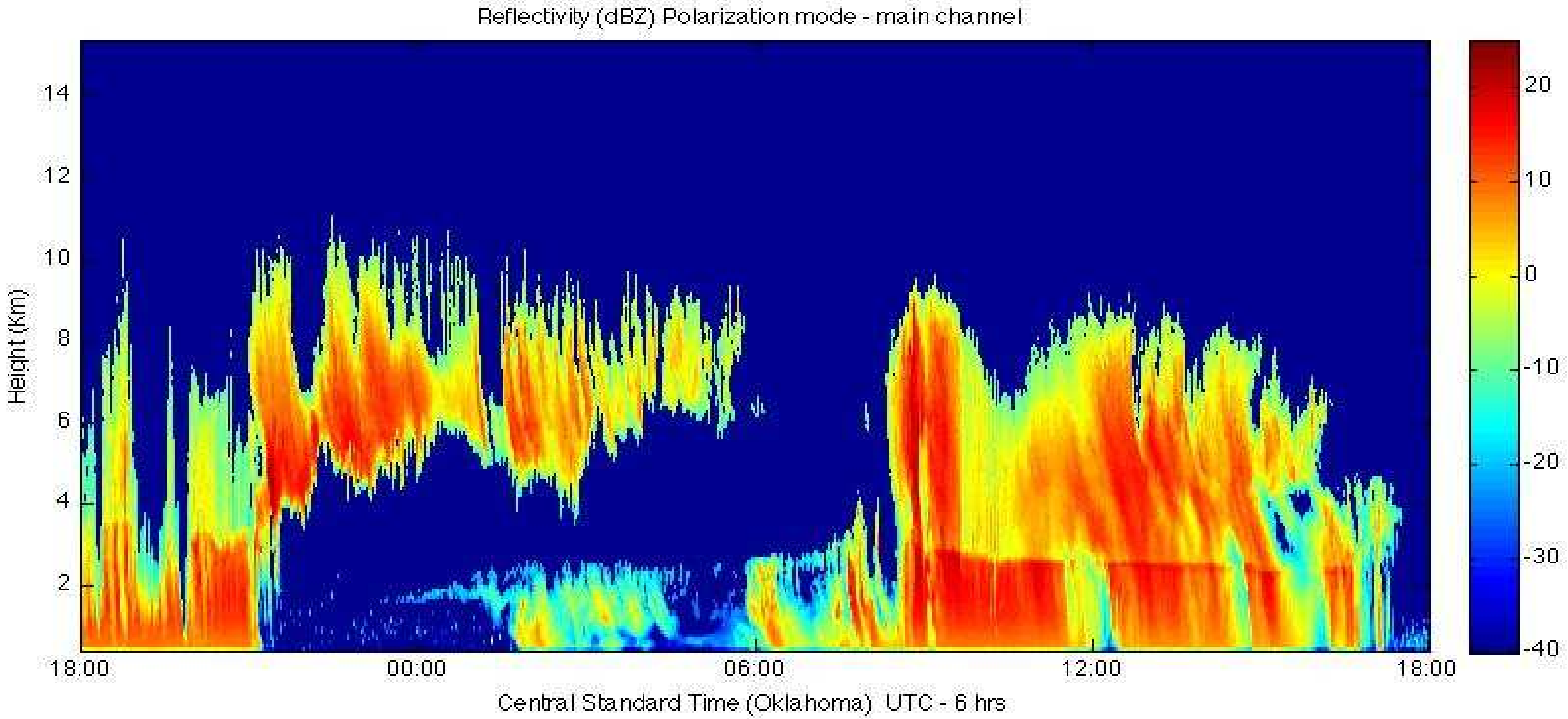
1 Boundary Layer mode
2 Cirrus mode
3 General mode

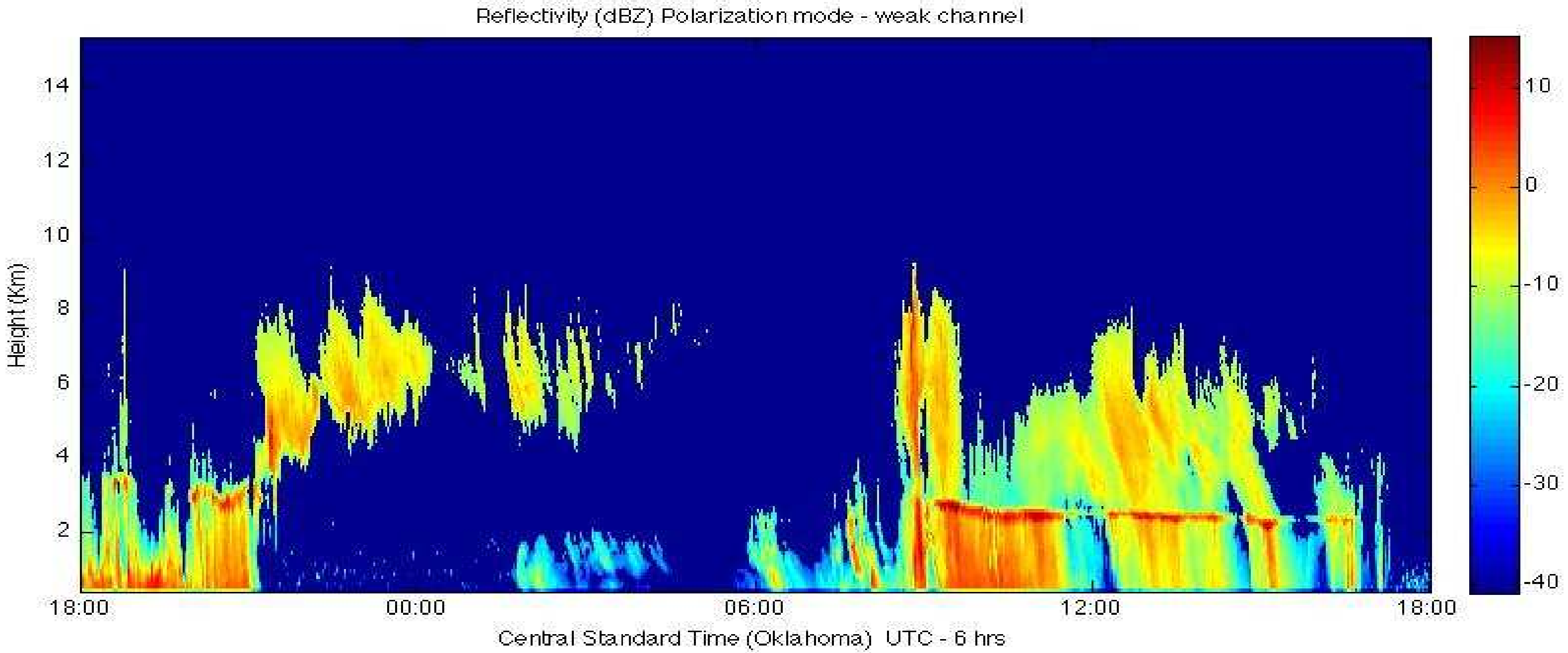
4 Precipitation mode → An attenuator is switched on at the radar front-end to prevent saturation in rain

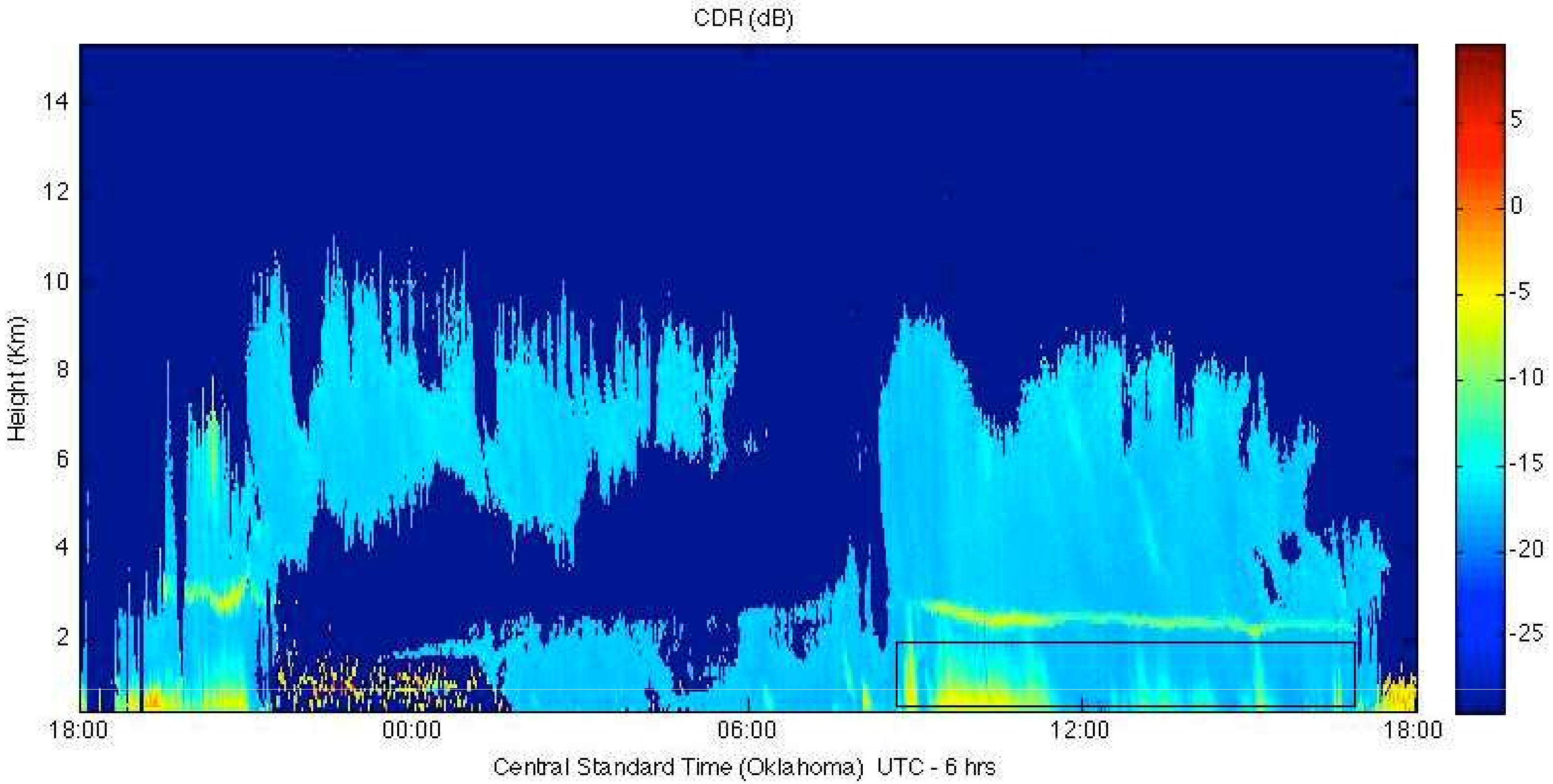
1 Main channel
2 Weak channel

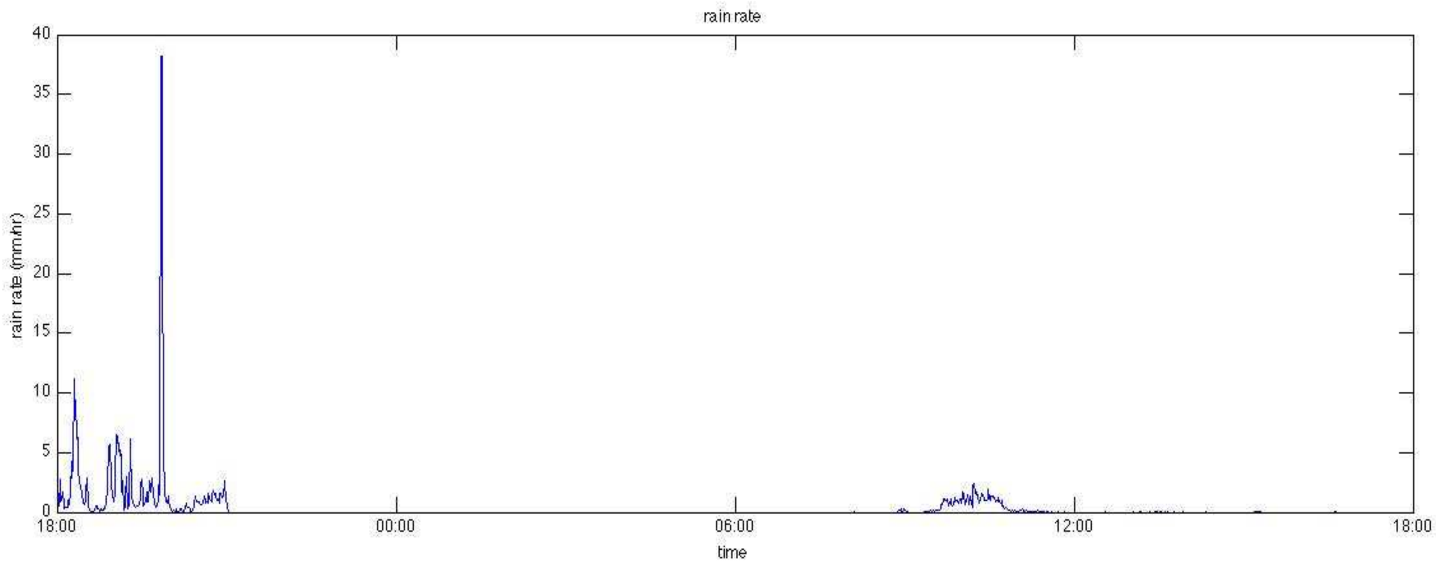
→ These channels are used to compute CDR. Mode 5 is very similar to mode 3

Case 1: April 29th 2006

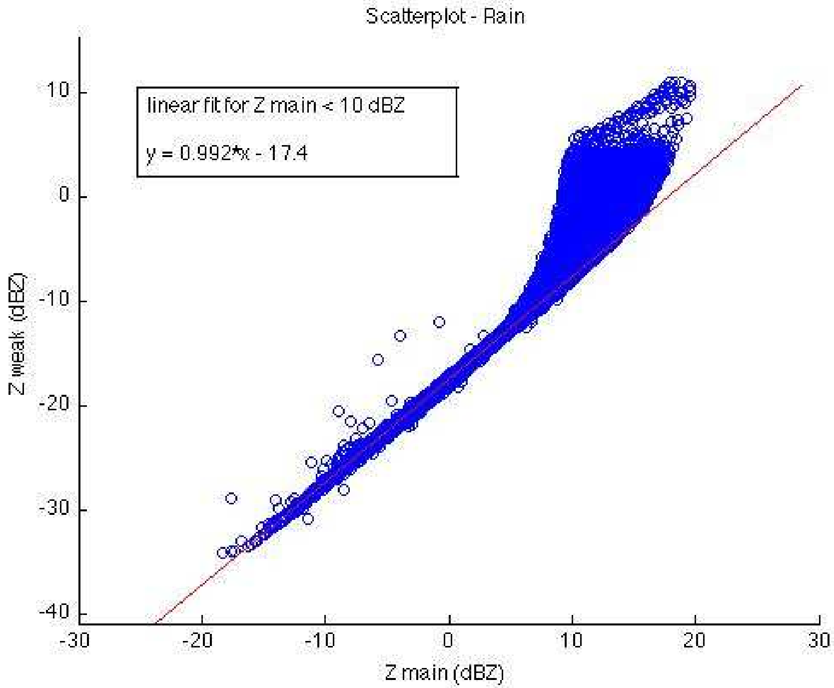

Reflectivity (dBZ) Polarization mode - main channel
Height (Km)
14
12
10
8
6
4
2
18:00
00:00
06:00
12:00
18:00
Central Standard Time (Oklahoma) UTC - 6 hrs
20
10
0
-10
-20
-30
-40


Reflectivity (dBZ) Polarization mode - weak channel
Height (Km)
14
12
10
8
6
4
2
18:00
00:00
06:00
12:00
18:00
Central Standard Time (Oklahoma) UTC - 6 hrs
10
0
-10
-20
-30
-40

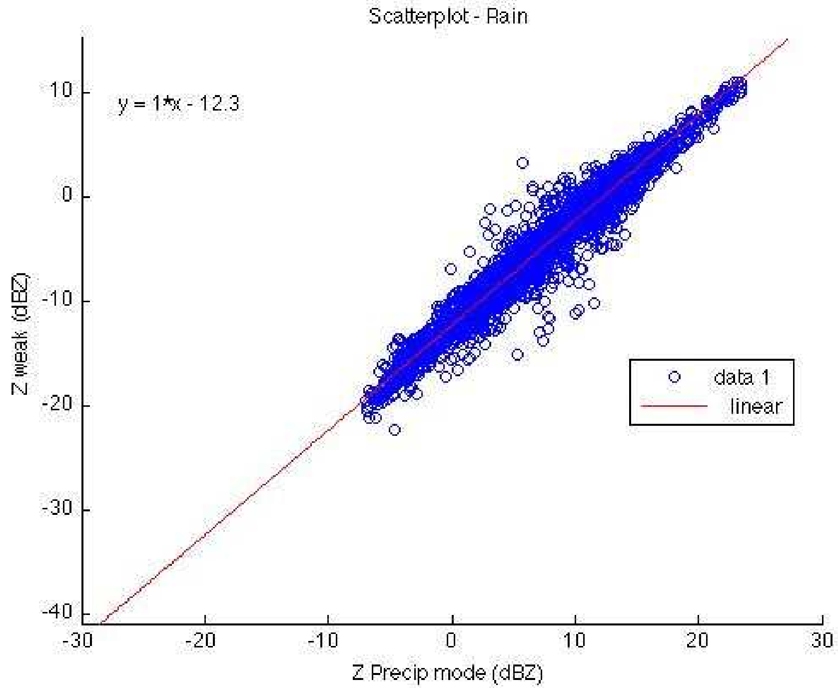

CDR (dB)
Height (Km)
14
12
10
8
6
4
2
18:00
00:00
06:00
12:00
18:00
Central Standard Time (Oklahoma) UTC - 6 hrs
5
0
-5
-10
-15
-20
-25


rain rate
rain rate (mm/hr)
40
35
30
25
20
15
10
5
0
18:00
00:00
06:00
12:00
18:00
time

The CDR flares we just saw are caused by saturation, not by raindrop oscillations !!



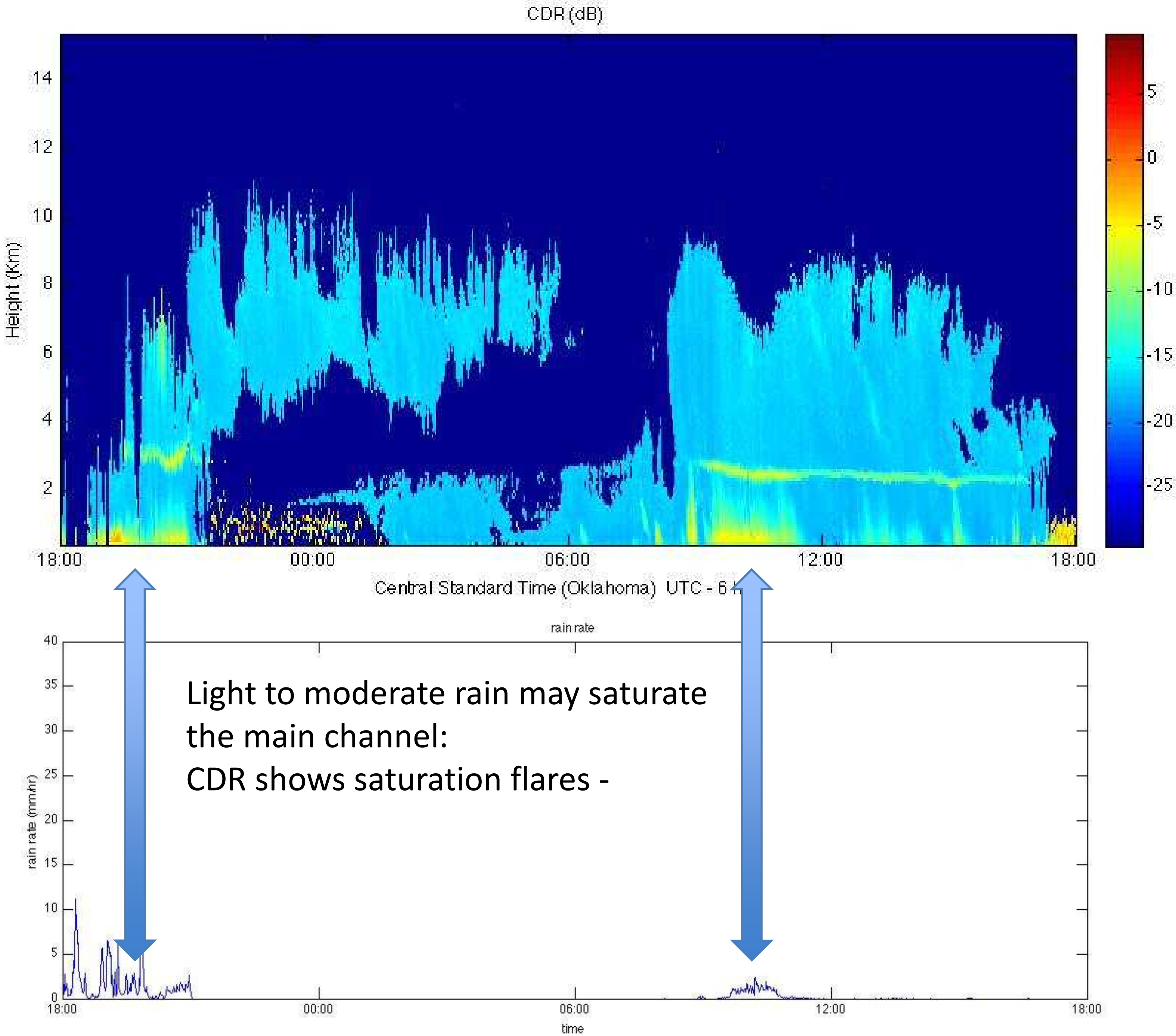
Reflectivity (mode 5) vs. Reflectivity (mode 6)



Reflectivity (mode 4) 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 !

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

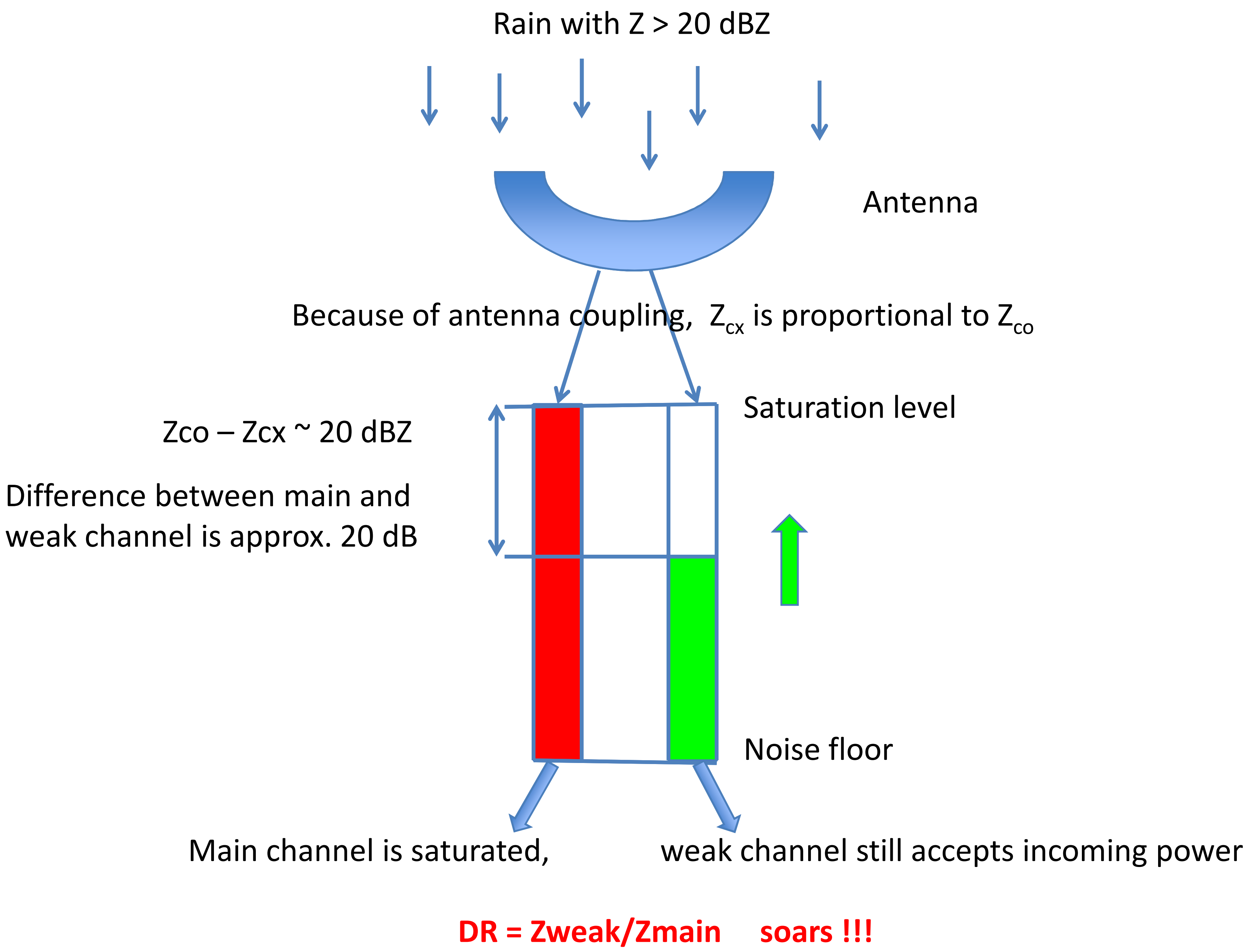


Light to moderate rain may saturate the main channel:

CDR shows saturation flares -

SATURATION FLARES

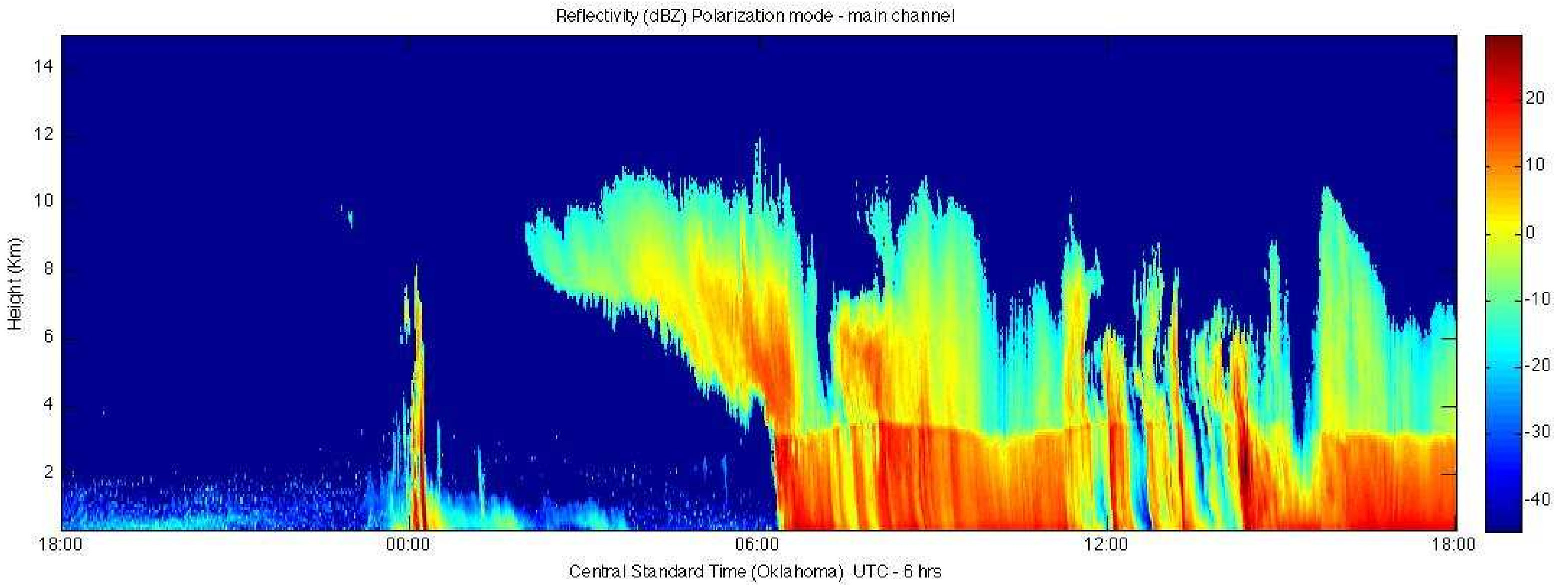
- Cloud radars are designed to detect clouds, generally, their dynamic range is between -60 dBZ and +20 dBZ
- In light (20 dBZ) and moderate (30 dBZ) rain, the main channel saturates....
- This induces spurious DR (Depolarization Ratio) flares at close ranges from the antenna.


Rain with Z > 20 dBZ
Antenna
Because of antenna coupling, Z_{cx} is proportional to Z_{co}
Saturation level
Zco – Zcx ~ 20 dBZ
Difference between main and weak channel is approx. 20 dB
Noise floor
Main channel is saturated,
weak channel still accepts incoming power
DR = Zweak/Zmain soars !!!

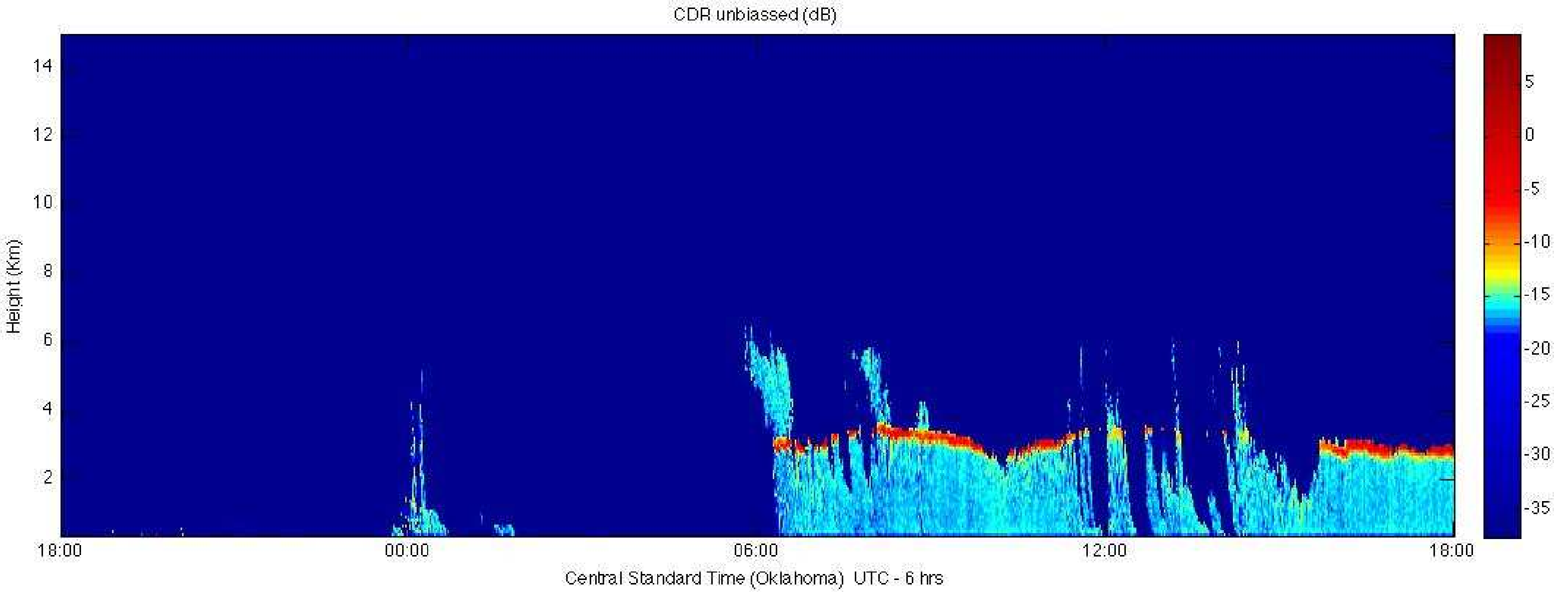
Depolarization Ratio signatures of non-axisymmetric drop oscillations

Case 2: May 7th 2008

Case 1: April 29th 2006

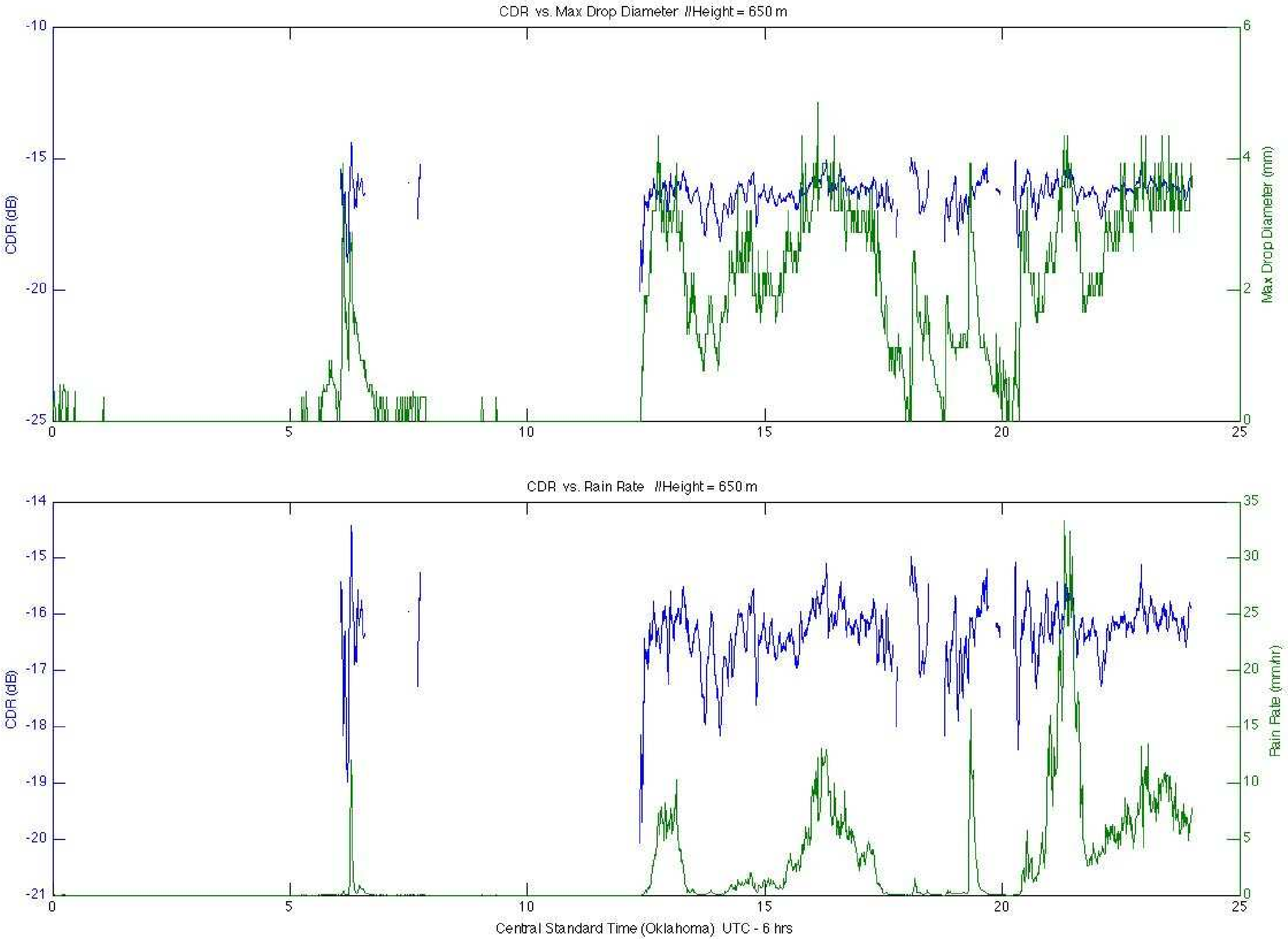


Reflectivity (dBZ) Polarization mode - main channel
Height (Km)
14
12
10
8
6
4
2
18:00
00:00
06:00
12:00
18:00
Central Standard Time (Oklahoma) UTC - 6 hrs
20
10
0
-10
-20
-30
-40



CDR unbiassed (dB)
Height (Km)
14
12
10
8
6
4
2
18:00
00:00
06:00
12:00
18:00
Central Standard Time (Oklahoma) UTC - 6 hrs
5
0
-5
-10
-15
-20
-25
-30
-35

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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