Cross-Coupling, Antenna Errors and Simultaneous Horizontal and Vertical Polarization Transmit Data

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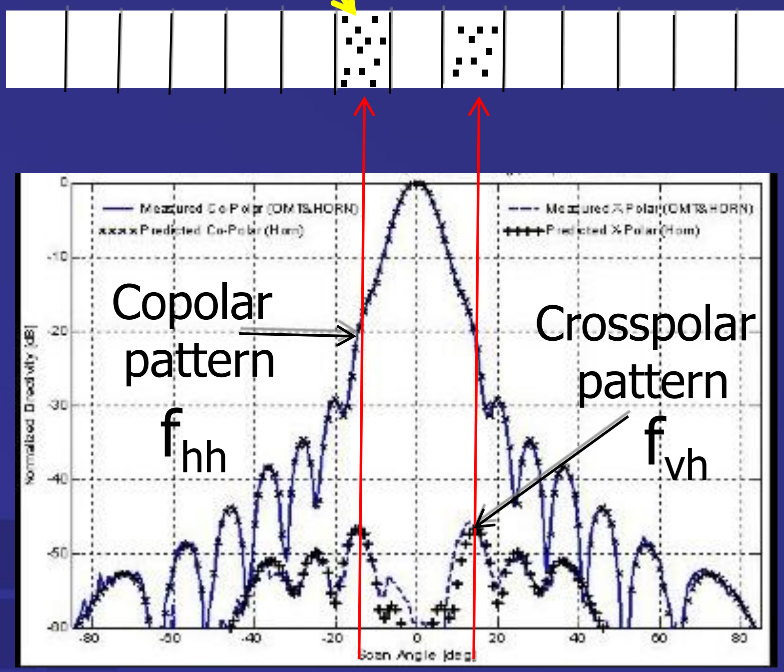
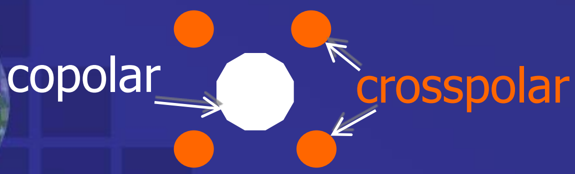
Cross-Coupling of the H and V Polarized Waves

- SHV operation is based on two assumptions:
  1. The mean canting angle of precipitation is zero
     - For rain this is a good assumption, but not for ice
  2. *Negligible antenna polarization errors*
     - *Is not well understood*

Crosspolar Received Signal.
Summing Across Antenna Patterns:
Incoherent Sum

$s_i = \sum \alpha_n$





α_n are the particle scattering amplitudes

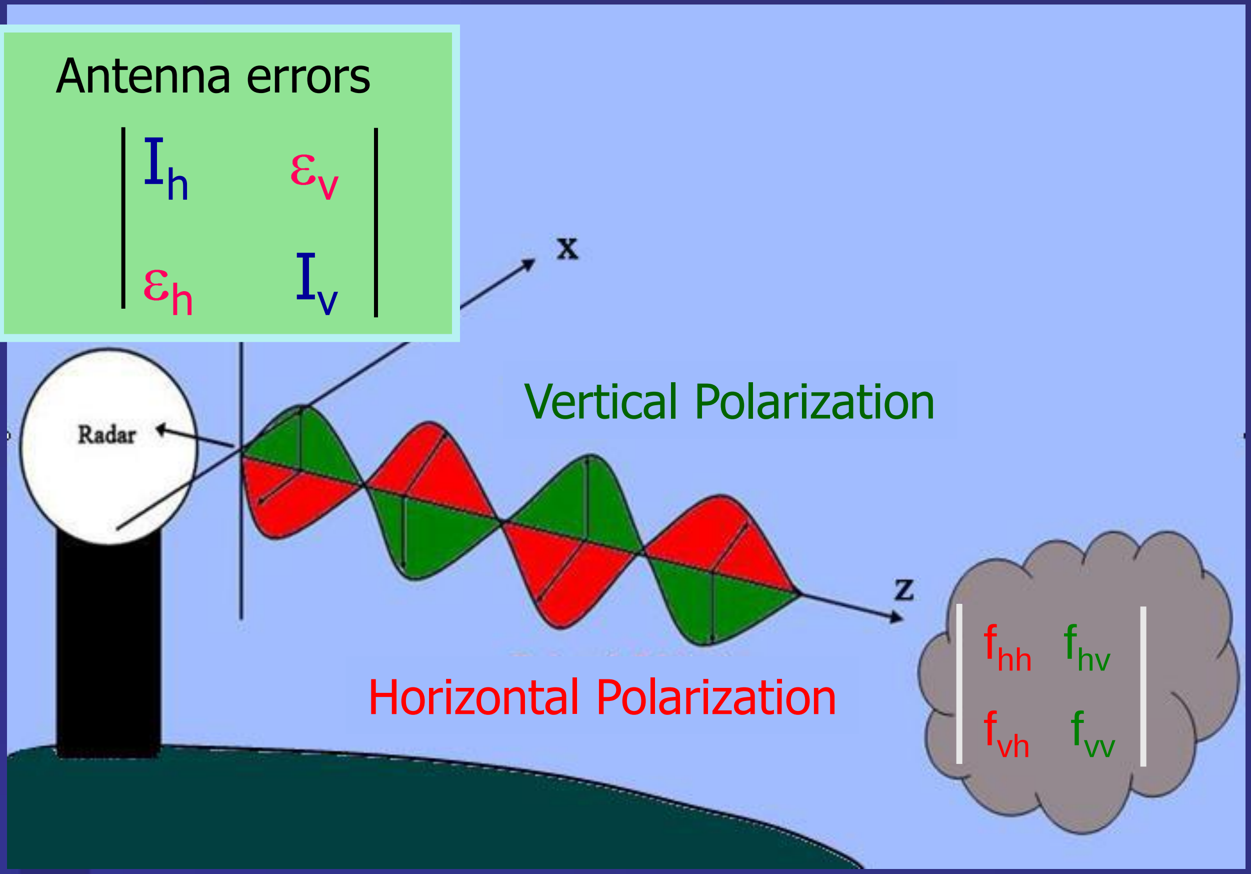
s_i are familiar backscattering amplitudes for an ensemble of randomly distributed particles. The real and imaginary parts are distributed Gaussian and the phase is uniform random , $-\pi$ to π (standard theory)

The received crosspolar signal is:

$$V_r = \sum \; f_{hh_i} \, s_i \, f_{vh_i}$$

Since each s_i is an independent RV (different resolution volume), this is an "incoherent sum" and f_{vh} peak lobes do not "cancel" (if 180 deg. out of phase).

Simultaneous H & V Transmission



$$\begin{vmatrix} I_h & \varepsilon_v \\ \varepsilon_h & I_v \end{vmatrix}$$

$$\begin{vmatrix} f_{hh} & f_{hv} \\ f_{vh} & f_{vv} \end{vmatrix}$$

Scattered Transmit

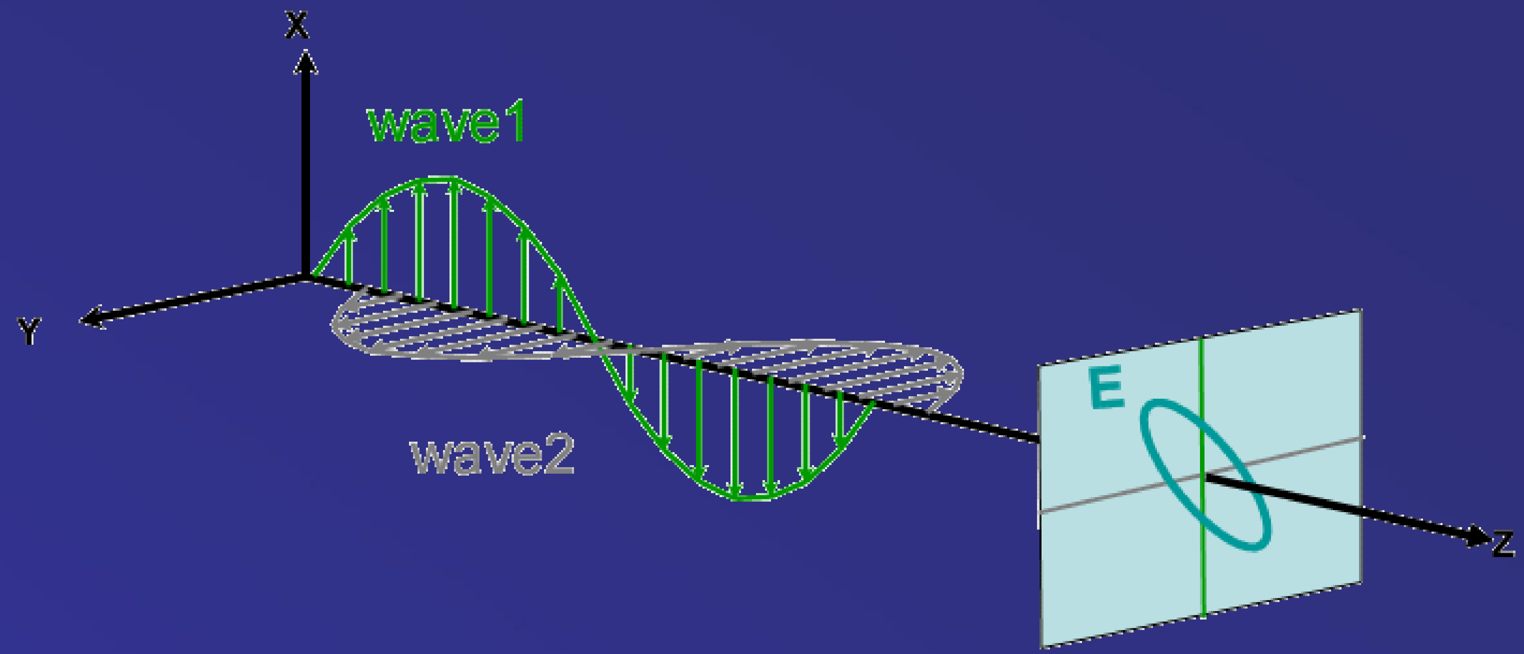
$$\begin{vmatrix} E_h^s \\ E_v^s \end{vmatrix} = \begin{vmatrix} f_{hh} & f_{hv} \\ f_{vh} & f_{vv} \end{vmatrix} \begin{vmatrix} E_h^t \\ E_v^t \end{vmatrix}$$

$$E_h^s = f_{hh} E_h^t + \boxed{f_{hv} E_v^t}$$

$$E_v^s = f_{vv} E_v^t + \boxed{f_{vh} E_h^t}$$

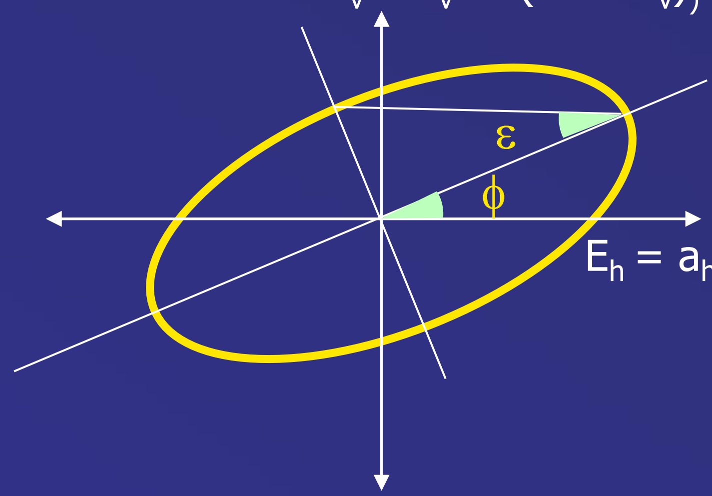
EOL Deployment Development Data Services

Polarization Ellipse



Describing Polarization States

Polarization Ellipse



Geometric parameters

ε ellipticity
ϕ tilt

Examples:

Horizontal: $\phi = 0, \ \varepsilon = 0$
Vertical: $\phi = 90, \varepsilon = 0$
Circular: $\phi = \cancel{0}, \ \varepsilon = +/-45$
Slant 45: $\phi = 45, \ \varepsilon = 0$
or $E_v = E_h$

2. SHV Z_{dr} Bias Due to Antenna Errors

- Wang and Chandrasekar, 2006, IEEE Transactions on Geoscience and Remote Sensing , *Polarization Isolation Requirements for Linear Dual-Polarization Weather Radar in Simultaneous Mode of Operation*

"to limit Z_{dr} errors to +/-0.2dB, 44dB isolation needed. Only 20dB isolation needed for fast alternating mode.."

Zdr should be calibrated to about 0.1 dB for 15% rainrate errors

But what is the expected isolation level due to typical antenna errors?
And what are typical antenna errors??

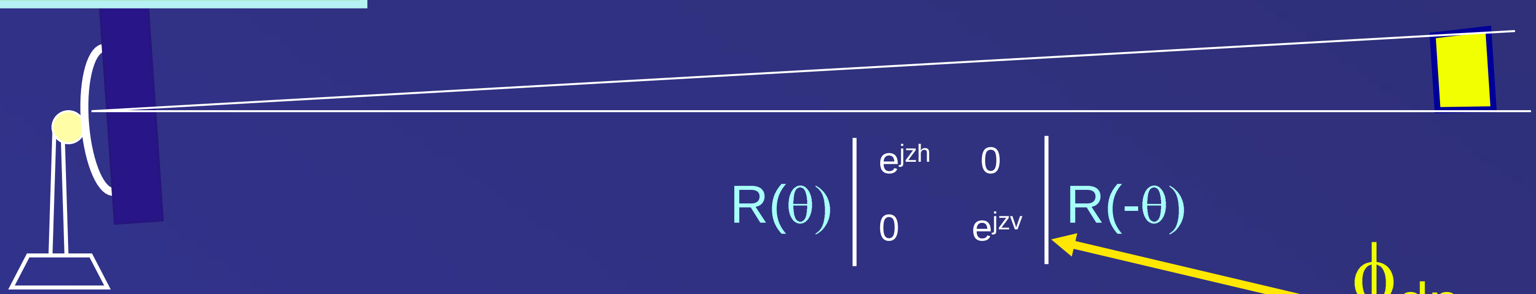
Radar Scattering Model

2. Antenna errors

$$\begin{vmatrix} I_h & \varepsilon_v \\ \varepsilon_h & I_v \end{vmatrix}$$

$$R(\alpha)\begin{vmatrix} \langle|S_{HH}|^2\rangle & \langle S_{HH}S_{HV}^*\rangle & \langle S_{HH}S_{VV}^*\rangle \\ \langle S_{HV}S_{HH}^*\rangle & \langle|S_{HV}|^2\rangle & \langle S_{HV}S_{VV}^*\rangle \\ \langle S_{VV}S_{HH}^*\rangle & \langle S_{VV}S_{HV}^*\rangle & \langle|S_{VV}|^2\rangle \end{vmatrix}R(-\alpha)$$

Backscatter medium



$$\begin{vmatrix} E_H^t \\ E_V^t \end{vmatrix}$$

$$R(\theta)\begin{vmatrix} e^{jzh} & 0 \\ 0 & e^{jzv} \end{vmatrix}R(-\theta)$$

ϕ_{dp}

Principal plane

Transmit

Propagation medium

- Mean canting angle (θ)
- Differential attenuation
- Absolute attenuation

$$\begin{vmatrix} E_H^r \\ E_V^r \end{vmatrix}$$

Receive

See Hubbert and Bringi 2003: Studies of the Polarimetric Covariance Matrix. Part II: Modeling and Polarization Errors, JTECH

What Are Reasonable Antenna Polarization Errors?

Figures of merit for antenna isolation:

- ICPR of -34 dB
- LDRs -30 to -35 dB (in drizzle)

Now relate this to antenna errors of tilt and ellipticity

Quantifying Antenna Errors

Broadcast pure horizontally polarized wave at the antenna. Some of the wave will be coupled to the V cross port due to antenna errors:

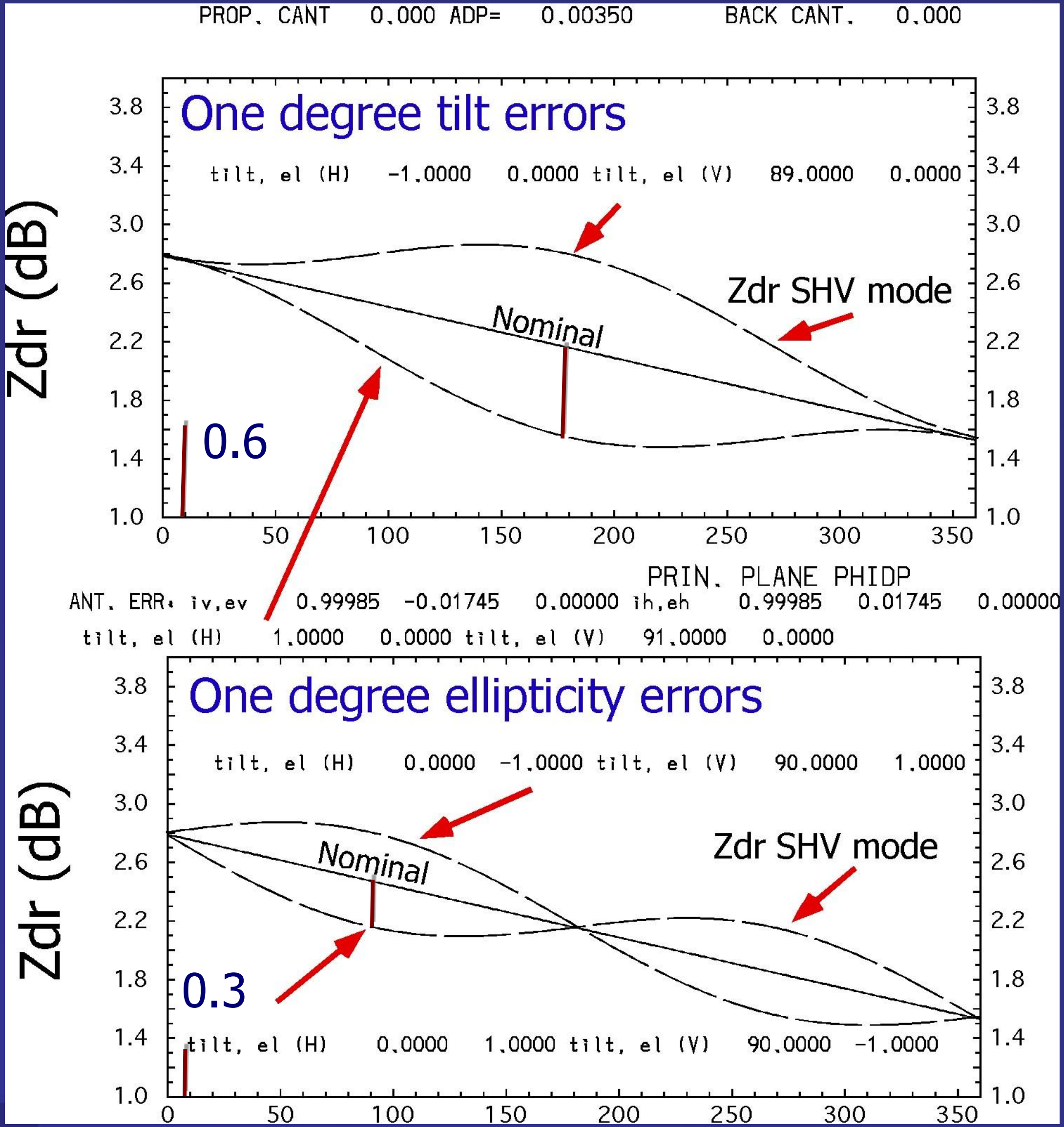
- IF $10 \log_{10} \dfrac{|E_v|^2}{|E_h|^2} = -35\text{dB}$, then

$$\text{inver. tan}\left(\frac{|E_v|}{|E_h|}\right) = 1 \text{ degree}$$

This then would be the "tilt" angle of the received "polarization ellipse"

LDR system limits of -35 to -30 dB correspond to antenna error angles of about 0.5 to 1 degree.

One Degree Antenna Polarization Errors
(about -30dB isolation)



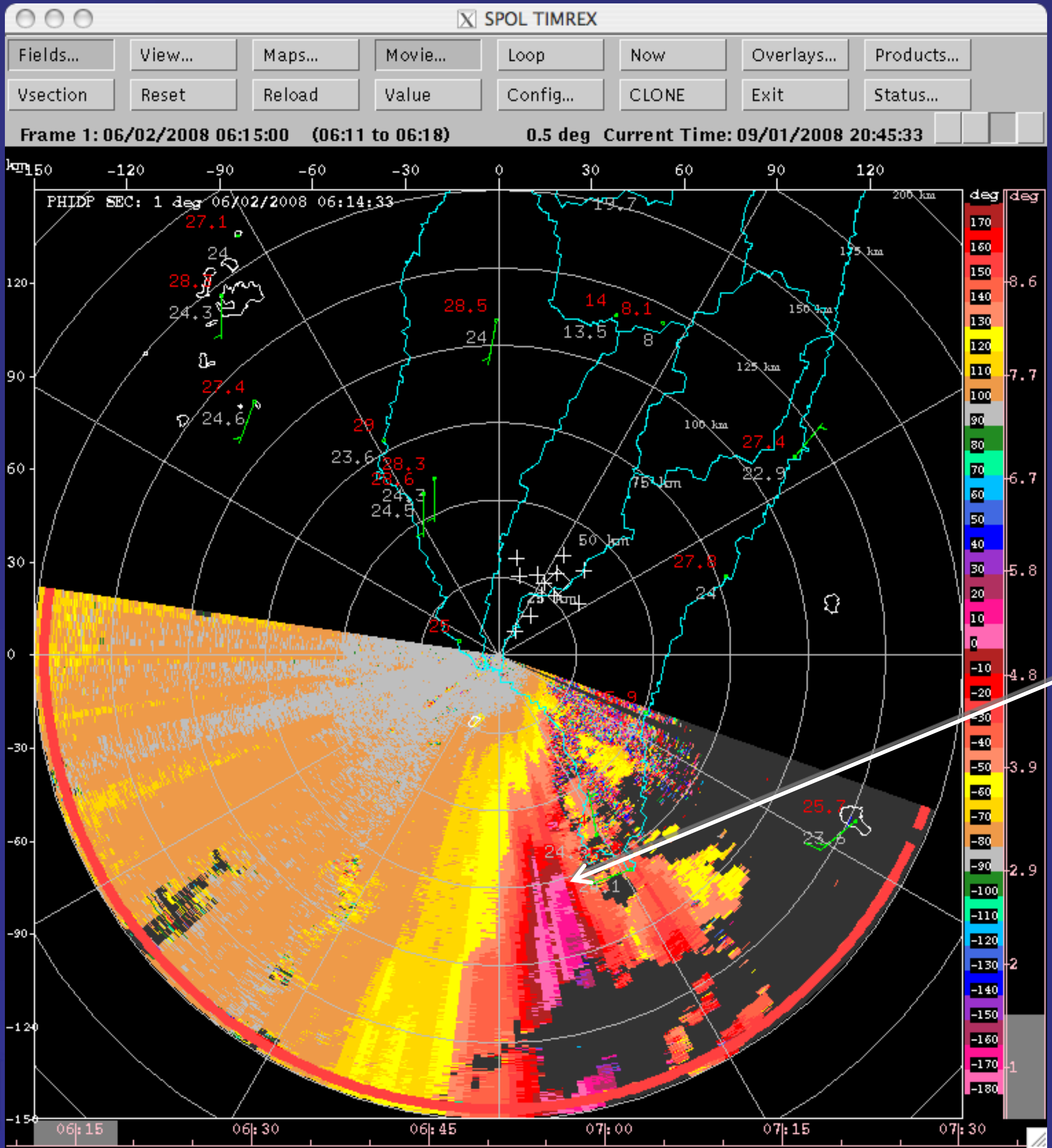
S-Pol Data from TiMREX

- Terrain-influenced Monsoon Rainfall Experiment. Taiwan, May-June 2008

- Both fast alternating H&V *and* simultaneous H&V data sets gathered within minutes of each other.

- First analysis of such data (to our knowledge)

S-Pol TiMREX ϕ_{dp}



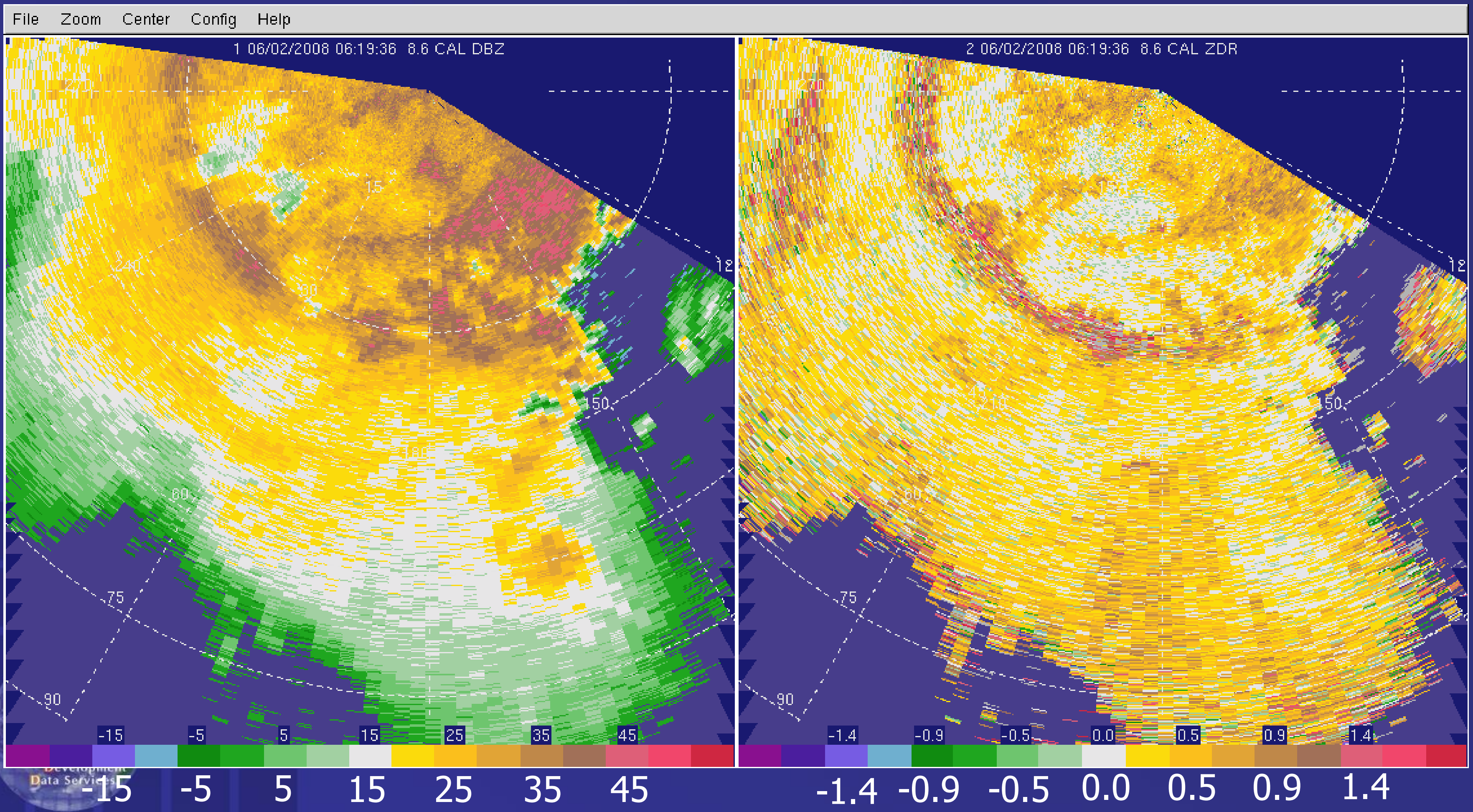
Over 100 degrees of phase shift

Fast Alternating H&V Transmit

at 8.6 deg elevation 06:19:36

Reflectivity (dBZ)

Differential Reflectivity (dB)

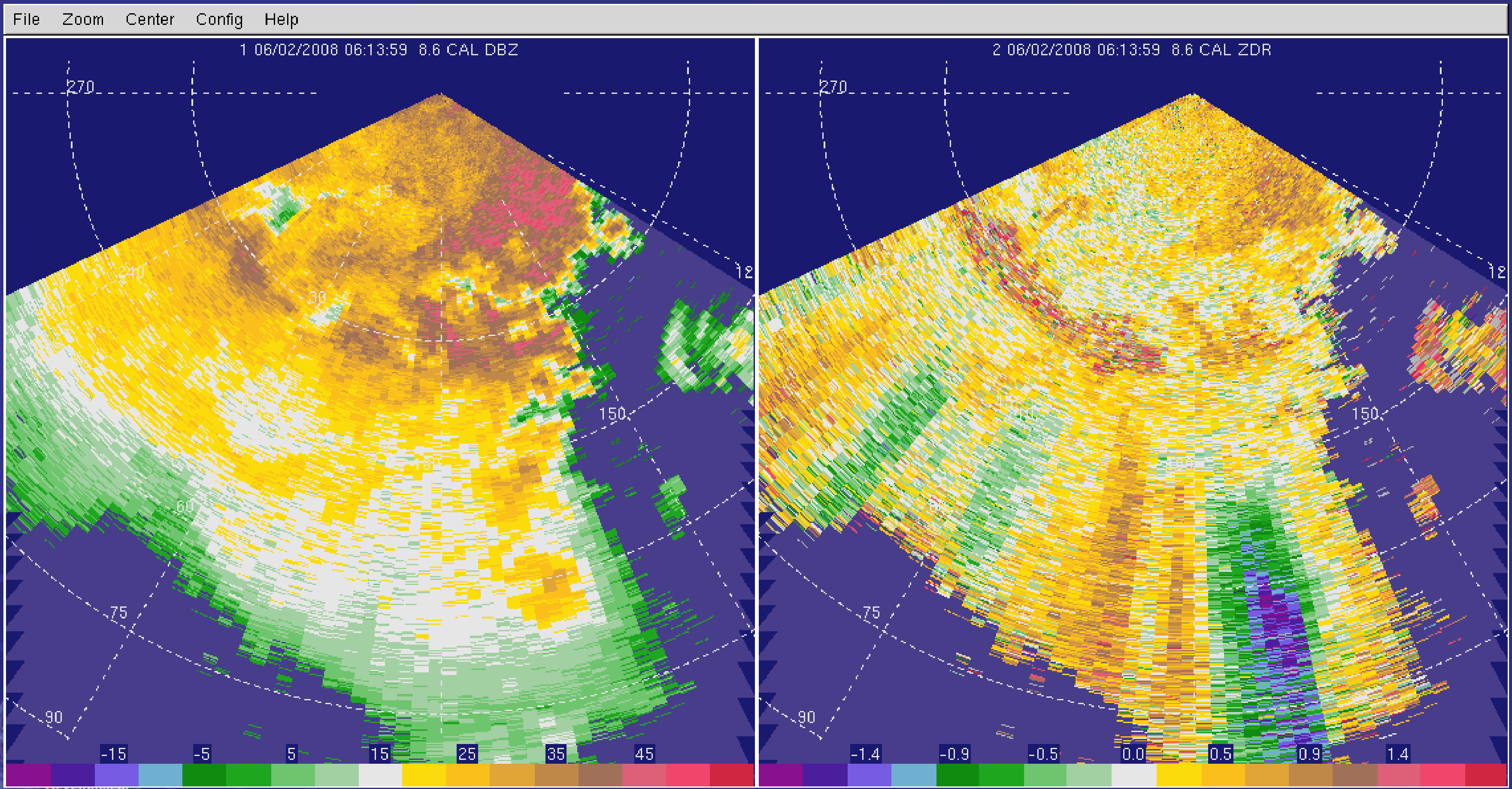


Simultaneous H&V Transmit

at 8.6 deg elevation. 06:13:59

Reflectivity (dBZ)

Differential Reflectivity (dB)

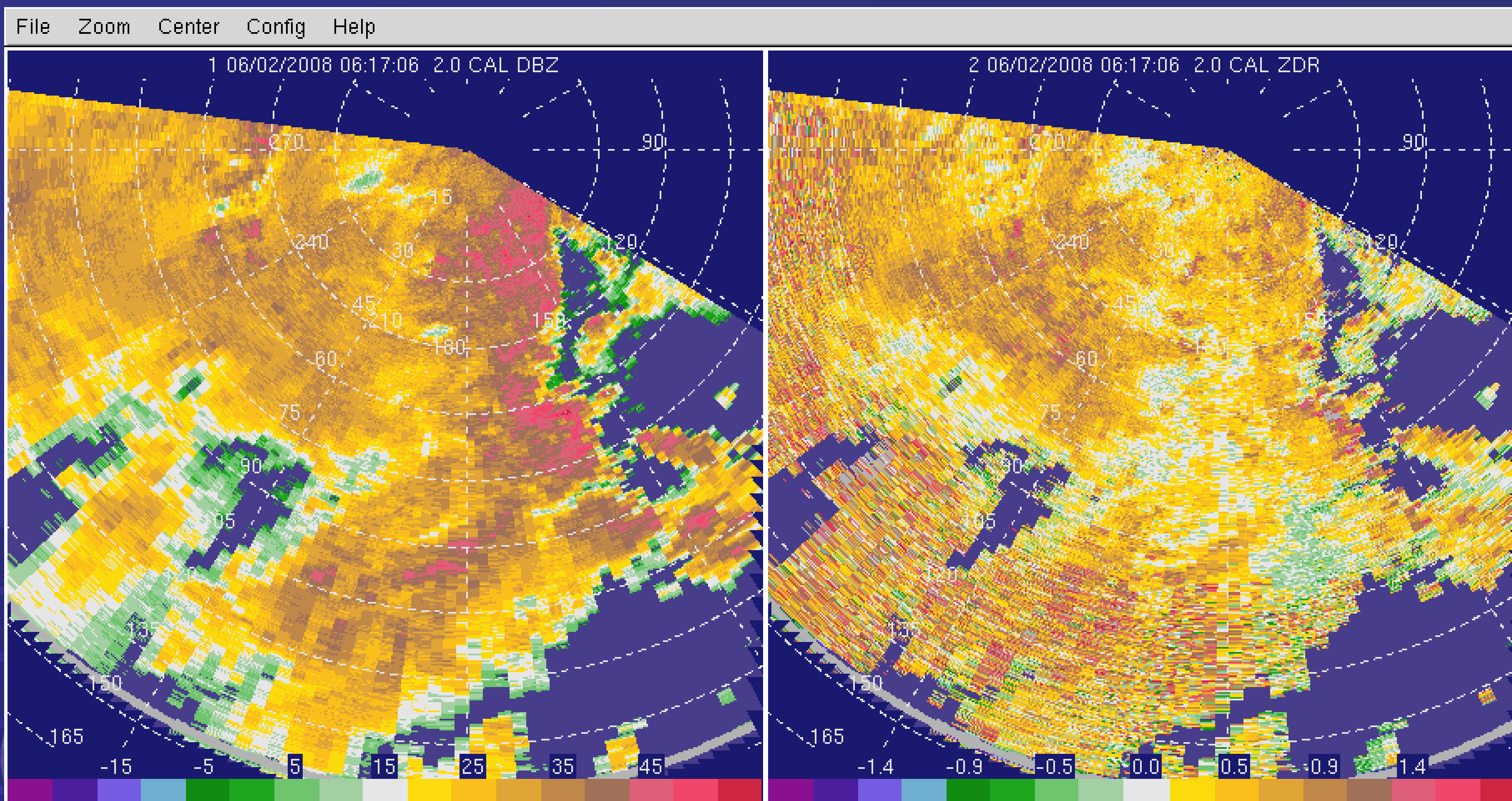


-15 -5 5 15 25 35 45

-1.4 -0.9 -0.5 0.0 0.5 0.9 1.4

Alternating Transmit at 2.0 deg elevation

Reflectivity (dBZ) | Differential Reflectivity (dB)



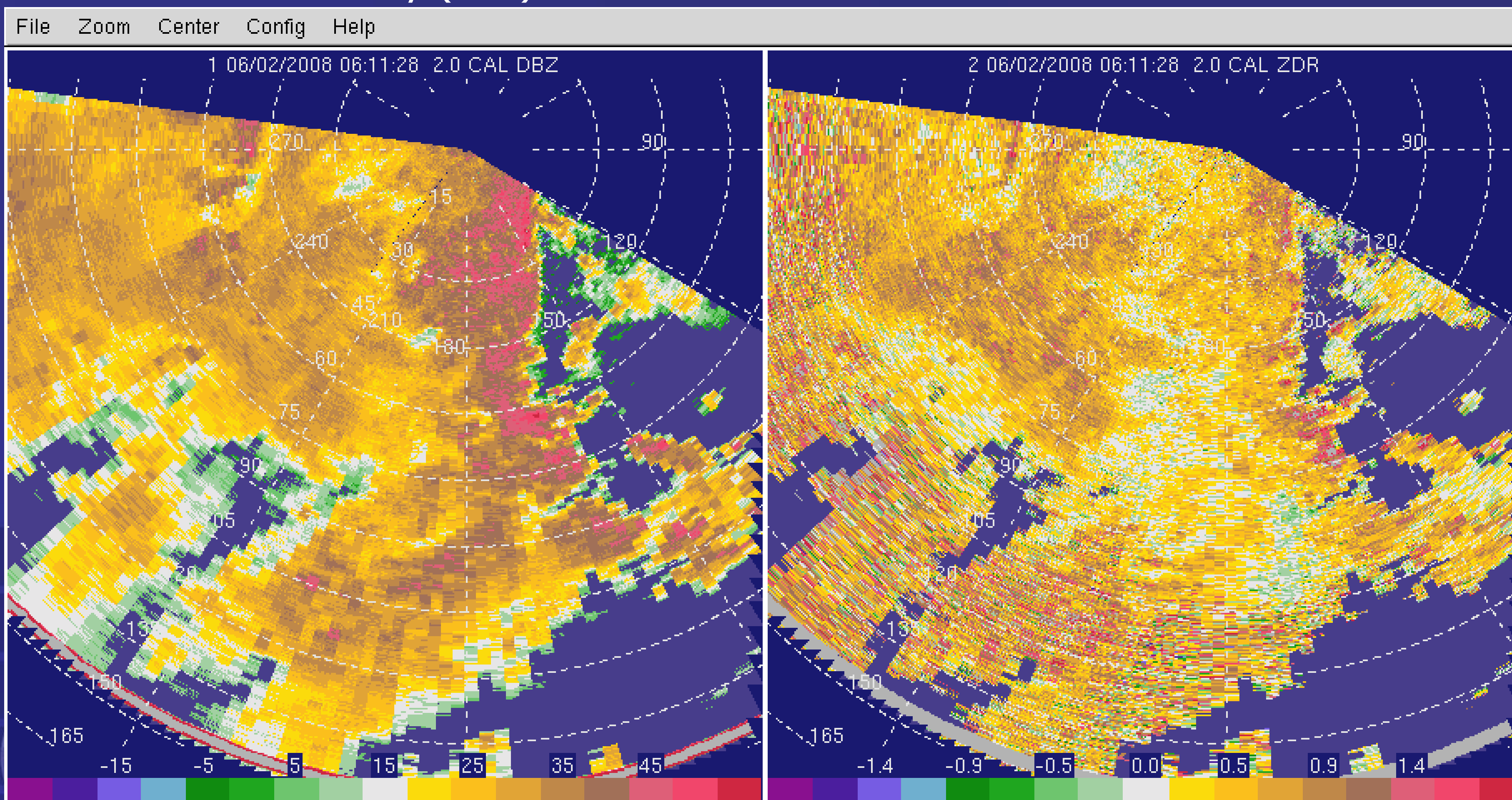
-15 -5 5 15 25 35 45

-1.4 -0.9 -0.5 0.0 0.5 0.9 1.4

Simultaneous Transmit at 2.0 deg elevation

Reflectivity (dBZ)

Differential Reflectivity (dB)



-15 -5 5 15 25 35 45

-1.4 -0.9 -0.5 0.0 0.5 0.9 1.4

Compare SHV and FHV Zdr

For 20 dBZ< Z < 25 dBZ

Total ϕ_{dp}	Mean Zdr (dB) FHV	SHV
between 20 and 40 deg	0.17	0.16
between 40 and 70 deg	0.15	0.26
between 70 and 100 deg	-0.07	0.20

As ϕ_{dp} increases SHV incurs positive Zdr bias

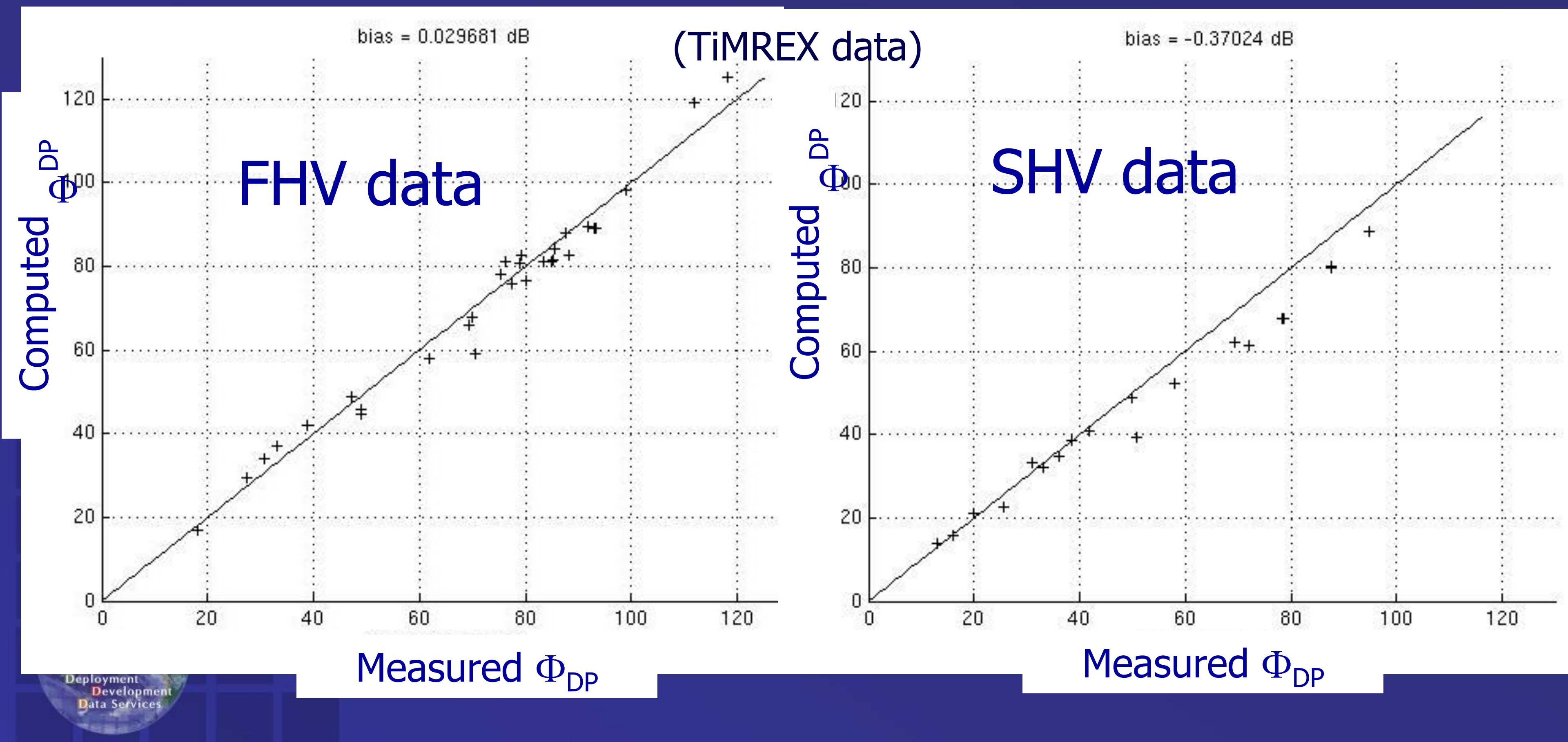
(no attenuation correction)

Power Calibration: Self-Consistency

- Compare ϕ_{dp} as estimated by Z, Zdr with ϕ_{dp} estimated directly from radar data
  - Requires approximate knowledge of DSD
  - Technique of Vivekanandan, et al., 2003
    - Avoid areas of hail
    - Correct for Zdr bias, first

Self Consistency Technique

For rain DSDs, Kdp, Zdr and Z have a predictable relationship. In this technique, measured Zdr and Z are used to predict ϕ_{dp} and judge if there is any Z bias.



Estimation of Antenna Errors, ε_h, ε_v

LDR system limit $\longrightarrow$ $(LDR_\ell)^{0.5} = |\varepsilon_h + \varepsilon_v| = 0.028$

Solar scan $\longrightarrow$ $Xcor = |\varepsilon_h^* + \varepsilon_v| = 0.004$

Since $|XCOR| << (LDR_\ell)^{0.5}$

The imaginary parts of $\varepsilon_h^* + \varepsilon_v$

must cancel significantly; i.e., $IM(\varepsilon_h) = IM(\varepsilon_v)$ (approx.)

This is equivalent to saying the antenna errors are dominated by the ellipticity angle error as opposed to canting angle error, and the *ellipticity angles are orthogonal.*

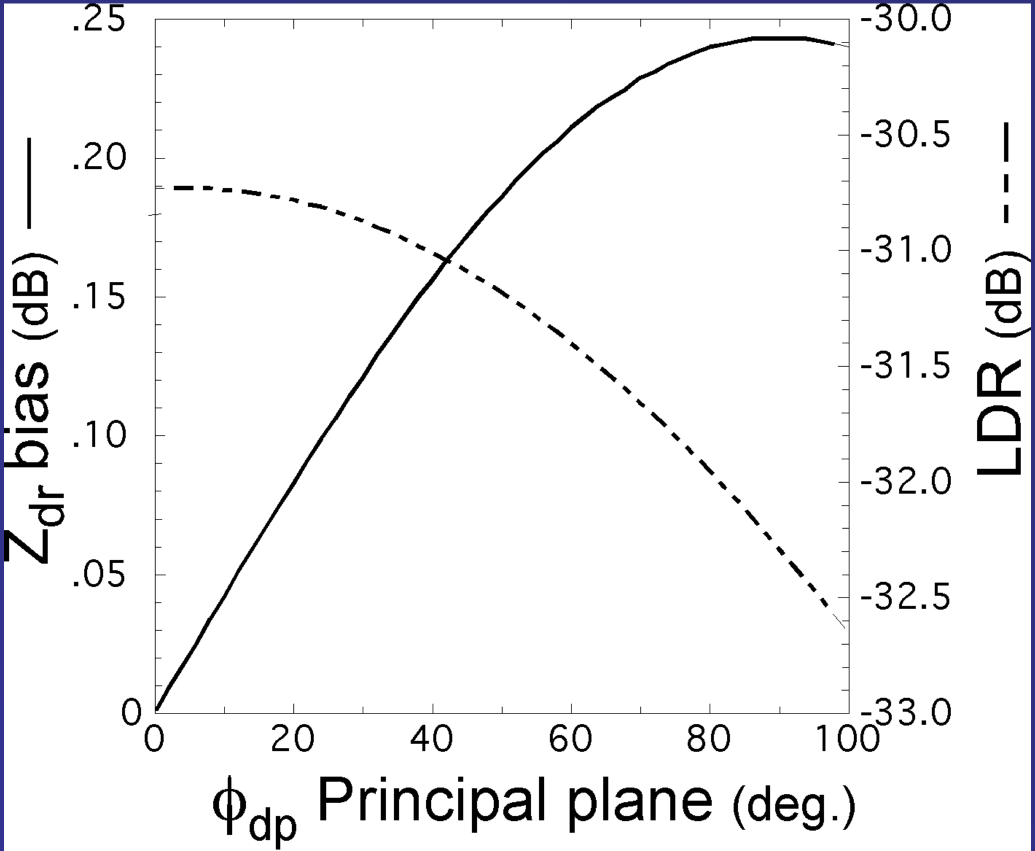
Deployment Development Data Services

Correcting S-Pol SHV Zdr

Using solar scan and LDR limit values, can calculate:

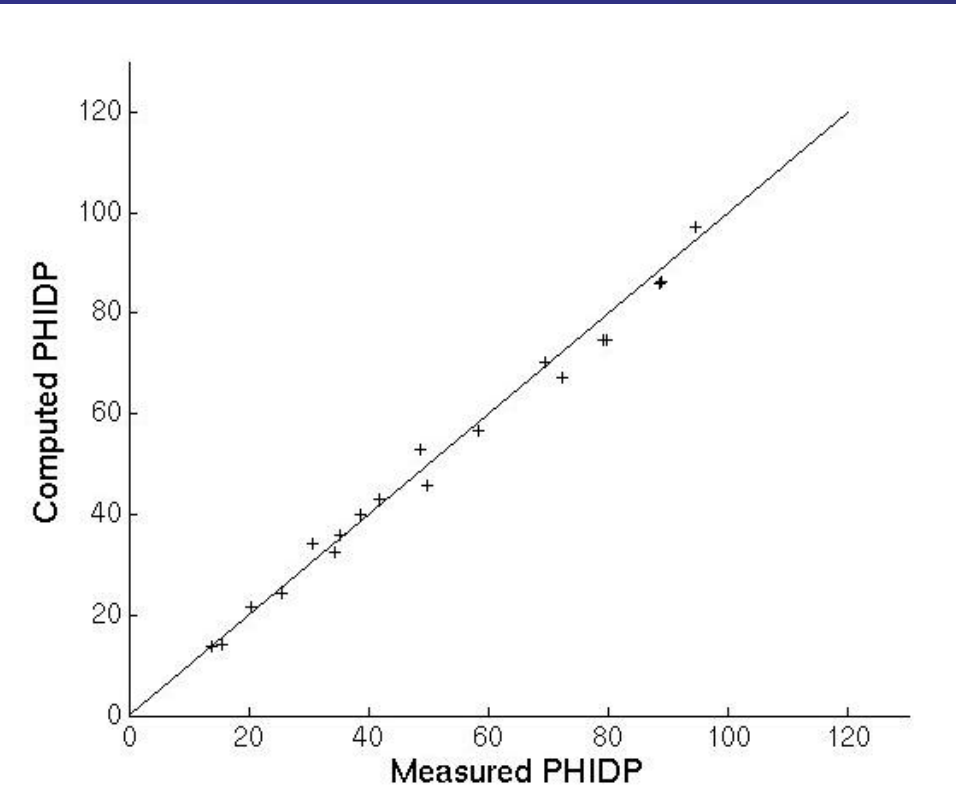
Tilt H = 0° , ellip H = 0.91° and tilt V= 90° , ellip V = −0.69°

From the model

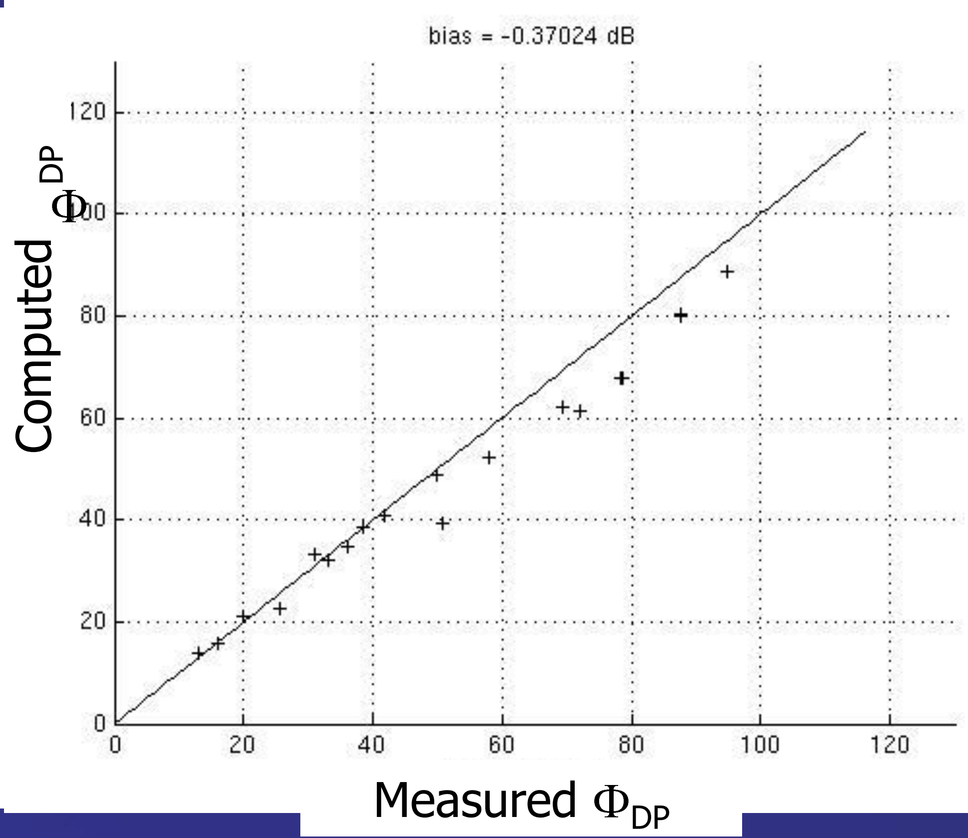


Corrected SHV Data

Corrected SHV data



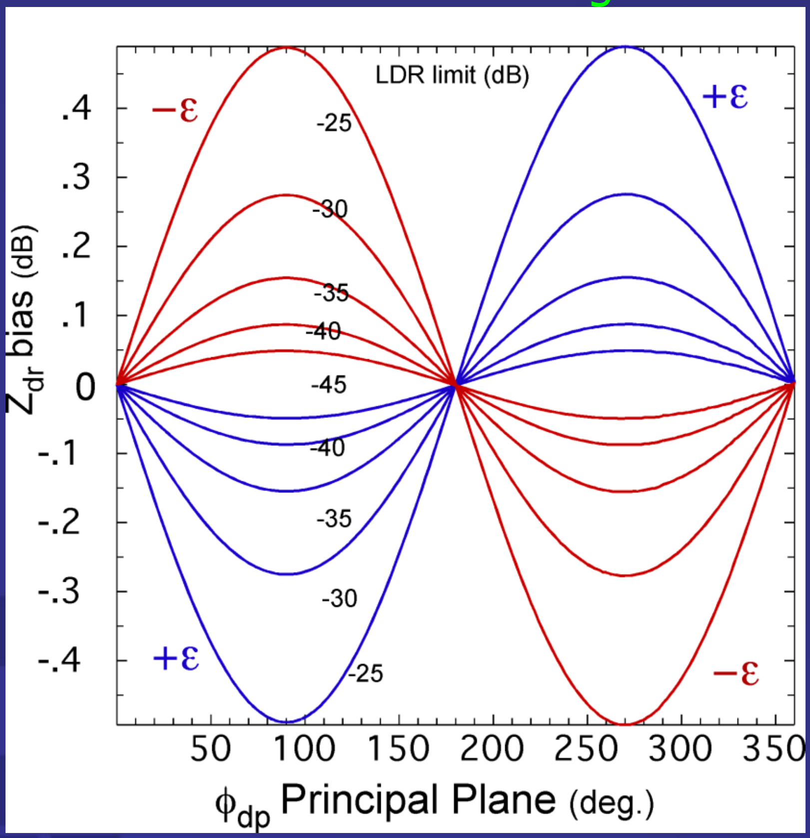
Uncorrected SHV data



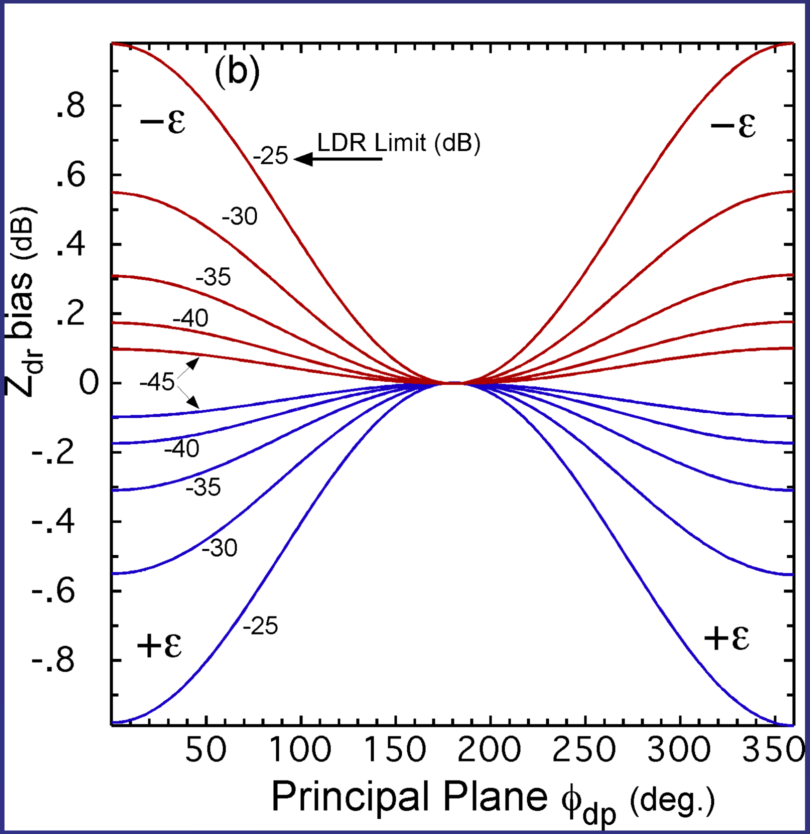
SHV Z_{dr} Bias Curves

Based on LDR system Limit with orthogonal ellipticity antenna errors

Transmit linear 45 degree



Transmit Circular

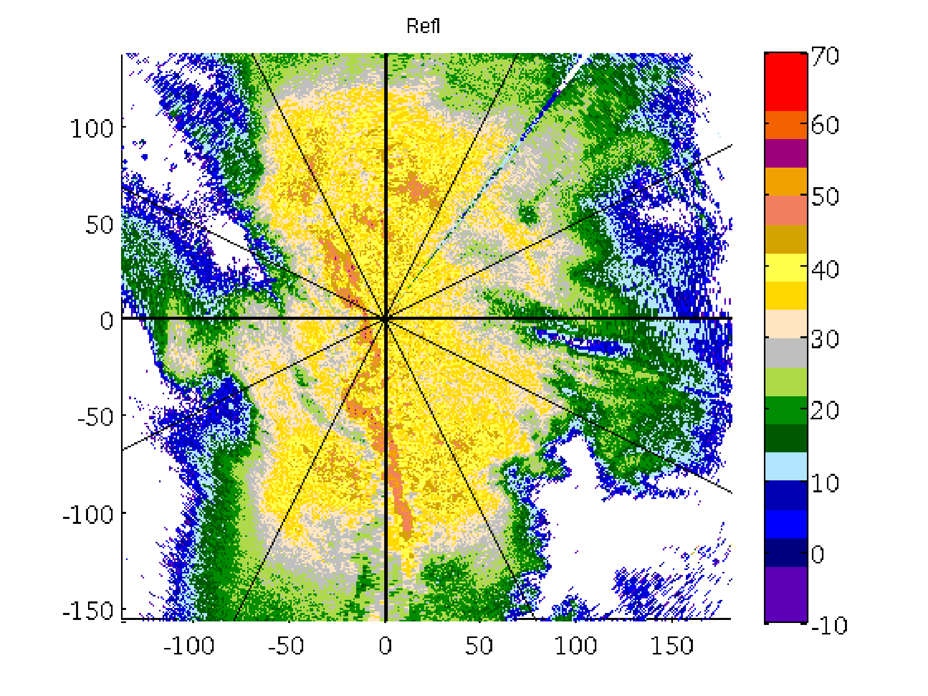


For SHV Z_{dr} < 0.2dB, LDR system limit < -40dB

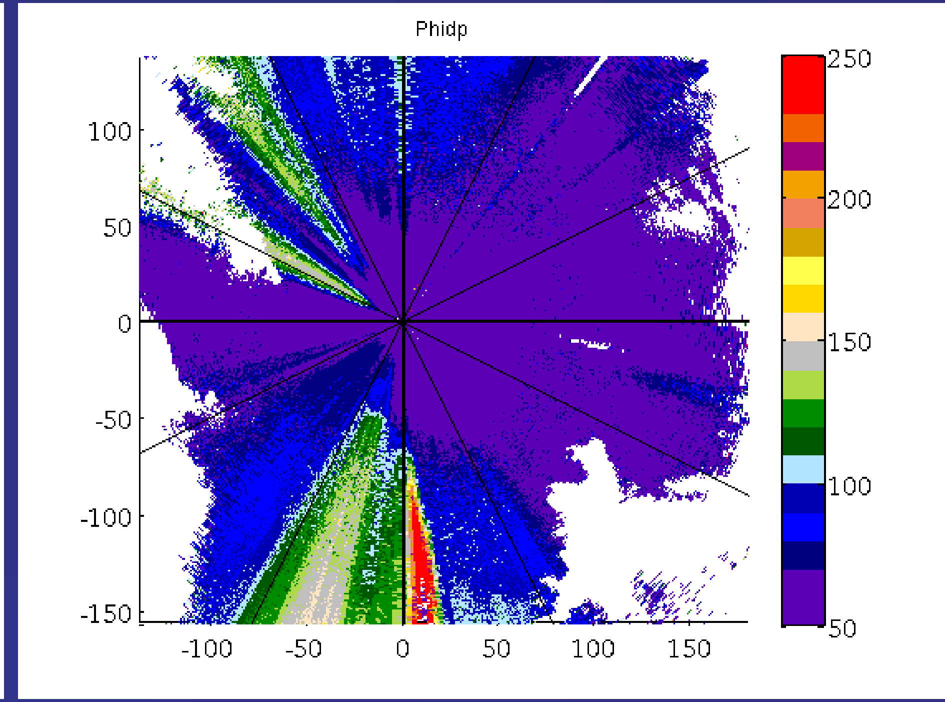
KOUN Data, 30 March 2007

- Large ϕ_{dp} case in rain: 300 degrees!
- Reported as more "tropical" in nature (few large drops)
- No hail reports from NWS or the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS)
- sounding data for the time period shows a moist profile through a deep layer, low vertical wind shear, and relatively low convective available potential energy (CAPE =834 J)

Z

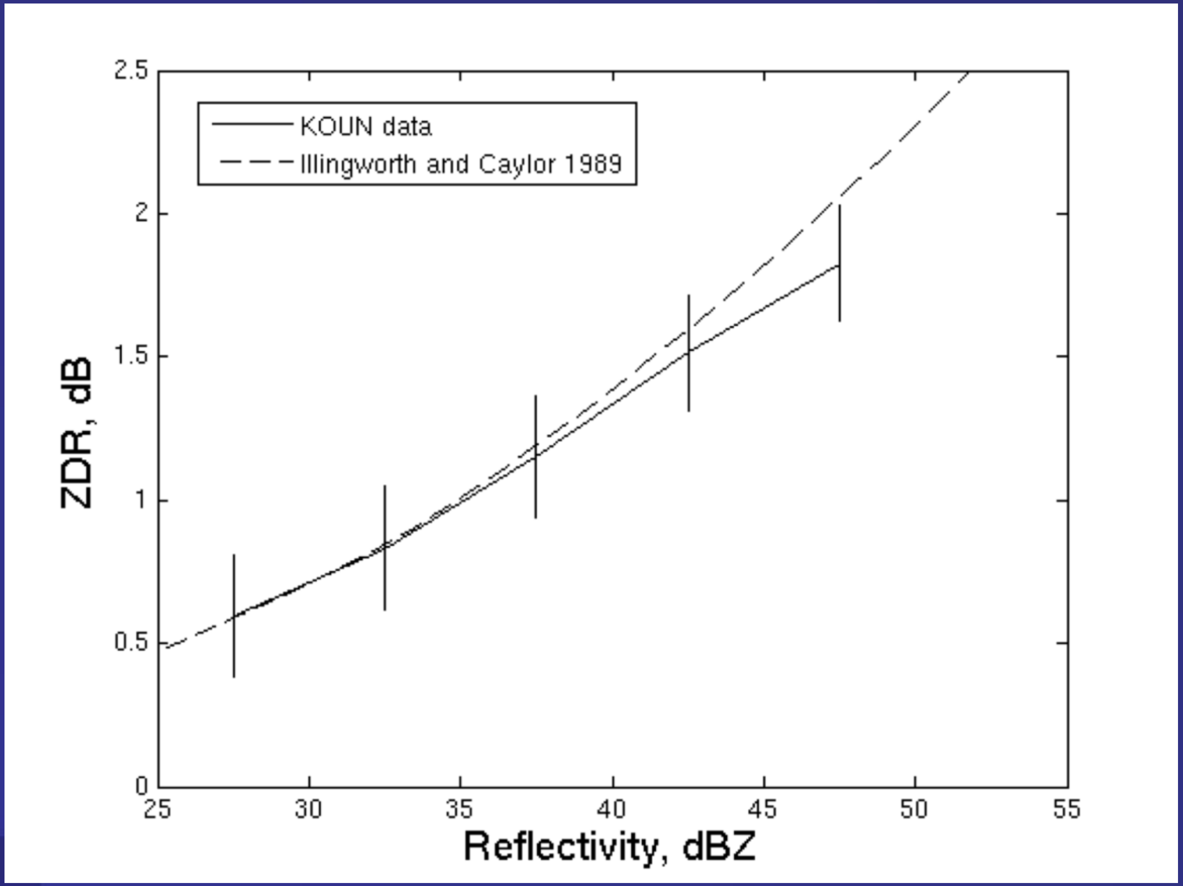


ϕ_{dp}



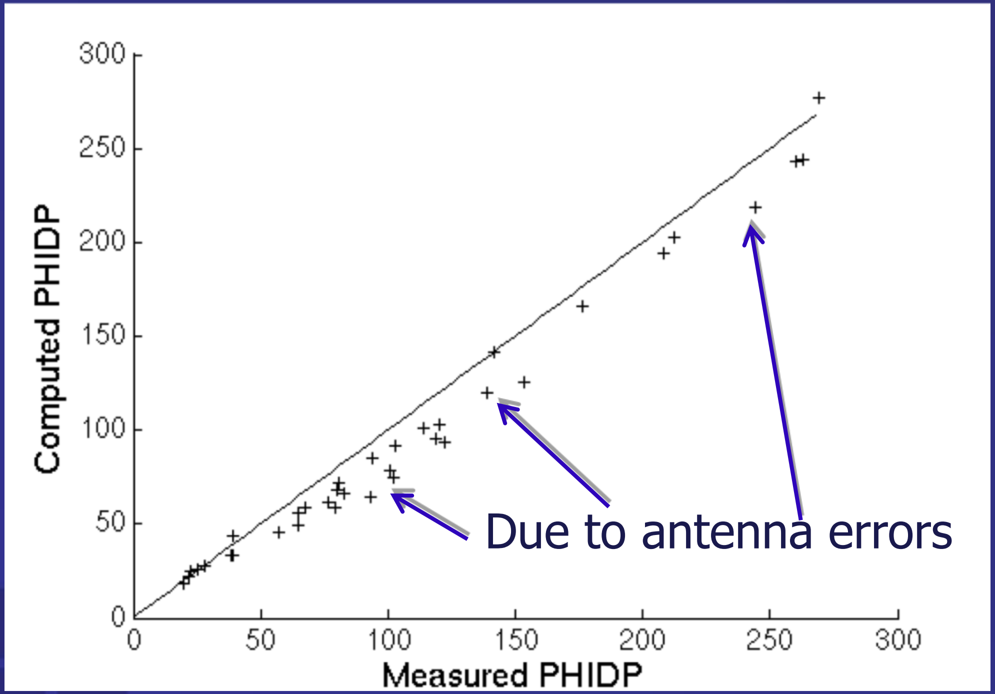
KOUN Calibration

- Data from rain with less than 30 deg. accumulative ϕ_{dp}
- Self consistency

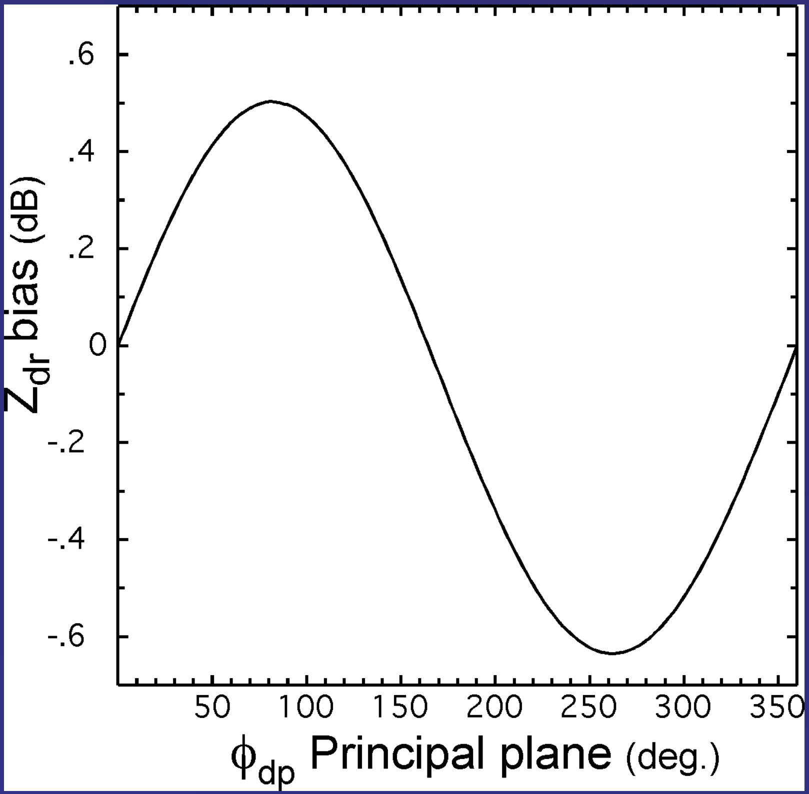


Koun Calibrated Data

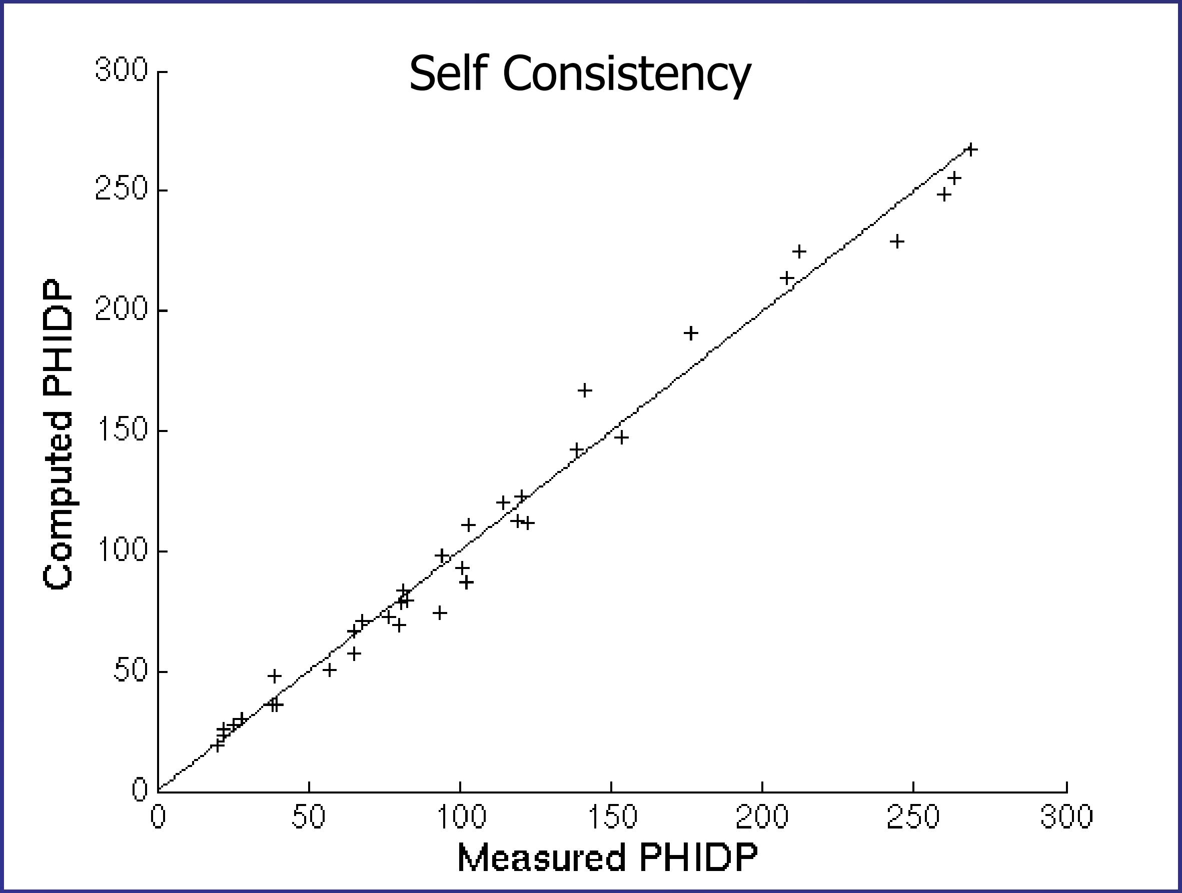
Self Consistency



Estimated Antenna Errors

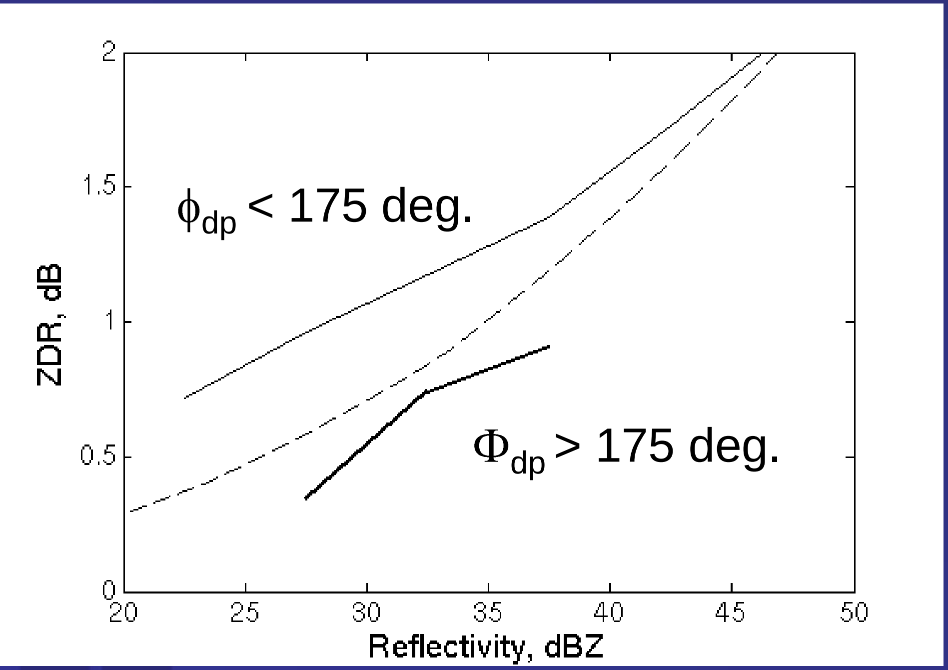


KOUN Data Corrected for Antenna Errors

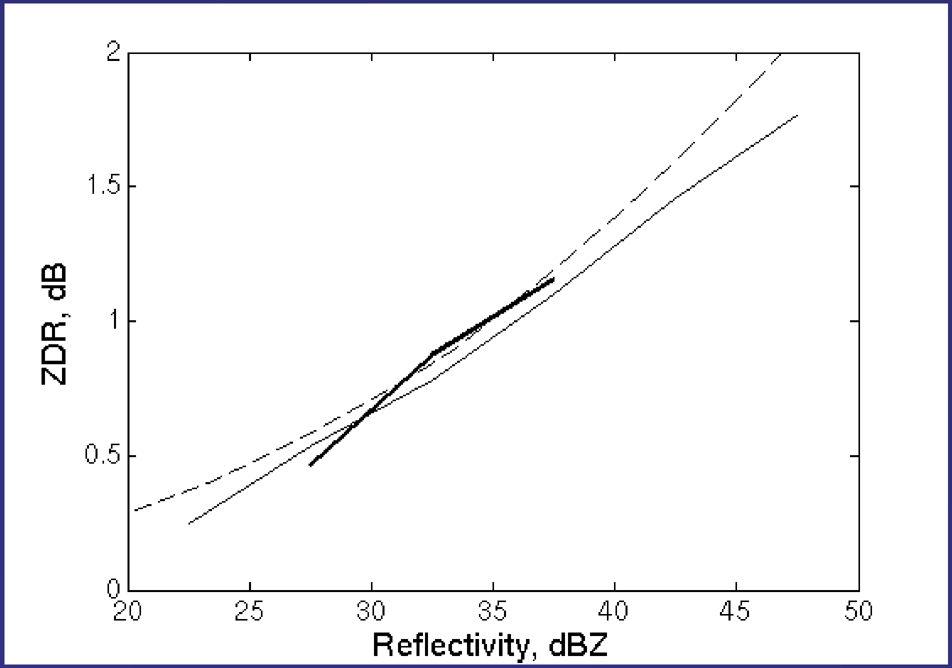


KOUN Z_{dr} Versus Z

Uncorrected Data



Corrected Data

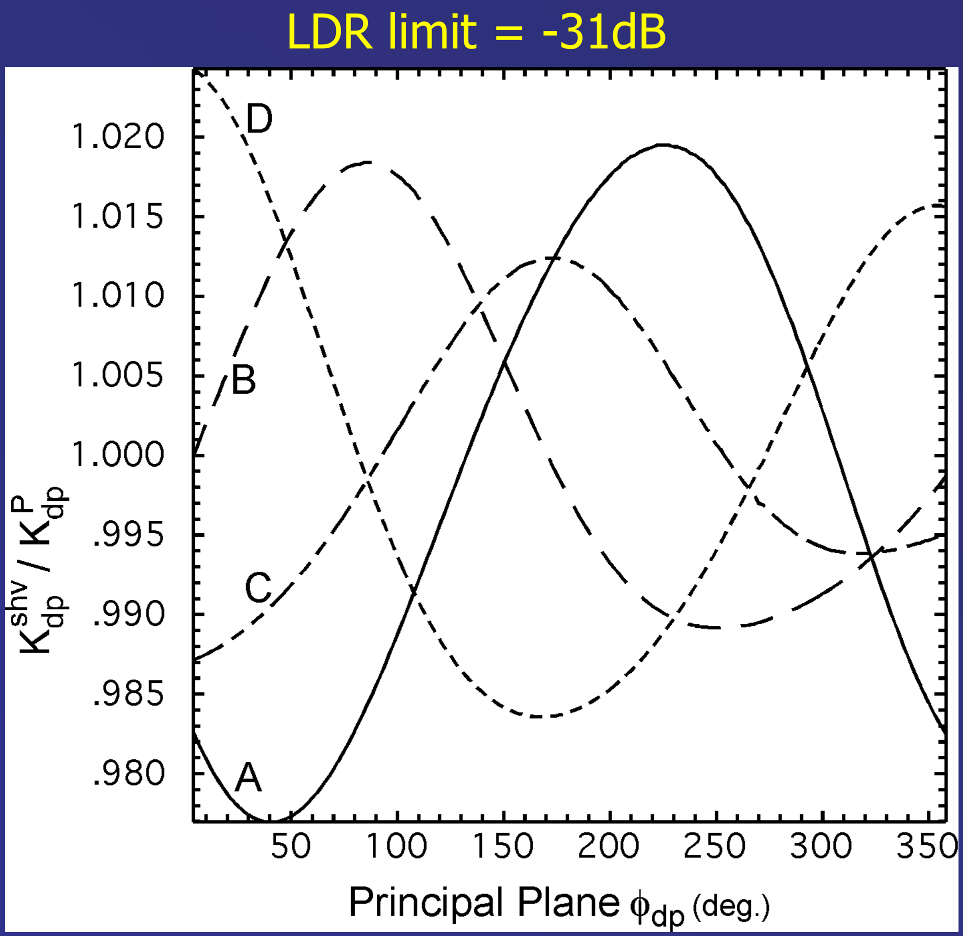


Deployment
Development
Data Services

Physical Polarization Error Sources

- Parabolic dish and support struts
- Feed horn, OMT (likely most significant)
- Radome effects
  - Seams
  - Wetting of the radome
  - Can polarization errors be a function of azimuth?
- What are the time variations of polarization errors?

Modeled SHV K_{dp} Errors



Conclusion: for larger accumulative phase shifts, do not use Zdr, use K_{dp}.
Zdr can be used for quality control

Conclusions

- All radars have imperfect antennas and therefore polarization errors
  - One can expect 0.3 to 0.5 dB max. bias in Zdr *in rain for weather radars with well designed center-fed parabolic antenna*
- To minimize cross coupling due to antenna polarization errors, the channel isolation should be as low as possible
  - For good dishes, the feed horn is likely the dominant error source
- The Zdr biases are a function of the transmit polarization state (phase difference).
- If Zdr bias is to be kept within +/- 0.1 dB, the LDR system limit needs to be < -45dB; +/- 0.2dB requires LDR < -40dB. Comparable conclusions by Wang and Chandrasekar.
- K_{dp}, is less biased than Z_{dr}

Thanks for your attention

Questions?