8A.4

Differential Reflectivity Calibration for Simultaneous Horizontal and Vertical Transmit Radars

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Vertical Pointing in Light Rain

- “Gold standard”
  - – End-to-end measurement
- But, rain many not occur frequently at radar site
- Radome wetting can play a role

There’s Another Way!

- Crosspolar power (CP) technique
- Also “end-to-end” technique
- Does not require rain at the radar

The CP Z_{dr} Calibration Technique

Reciprocity: $S_{hv} = S_{vh}$

Scattering Matrix: $E_r = \begin{pmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{pmatrix} E_i$

Reciprocity applies over the entire antenna pattern!!

Crosspolar powers are equal!!

Z_{dr} Calibration Equation

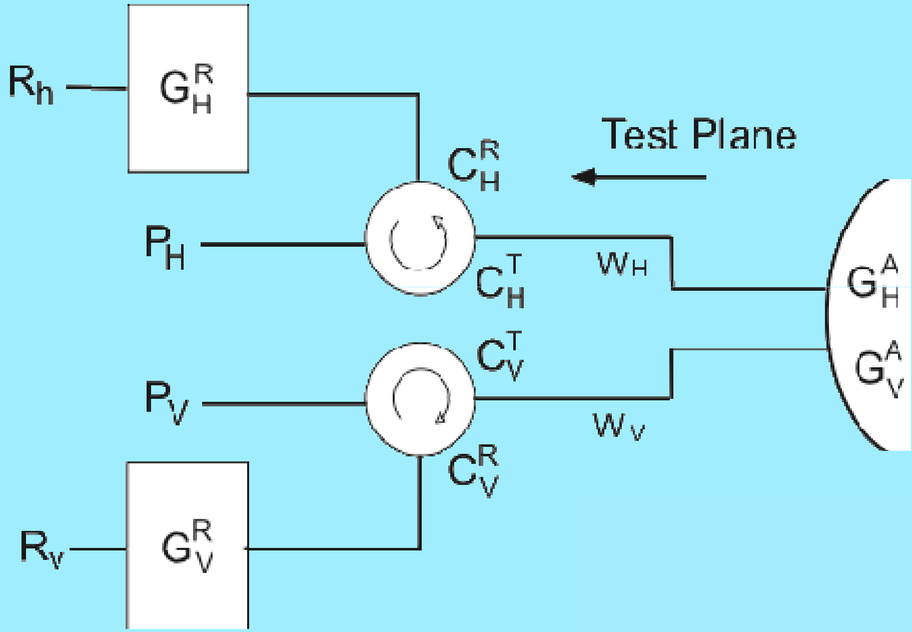
$$Z_{dr} = Z_{dr}^{m} S^{2} \overline{\left(\frac{R_{HVHV}}{R_{VHVH}} \right)}$$

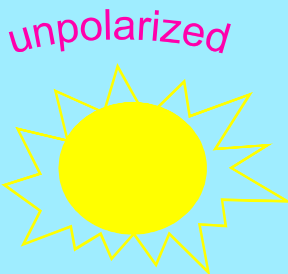
- Where S is a ratio of V to H passive sun powers
- R_{HVHV}, R_{VHVH} are the two crosspolar powers

  - ➢Need to be measured well with in target decorrelation time

    - ✓*The sun fills the radar beam well*
    - ✓*The crosspolar powers are independent of the antenna patterns*

Simple Block Diagram





Can use weather targets for X-pol pole power measurements for fast alternating H and V transmission data!

CP Z_{dr} Calibration

Z_{dr} intrinsic

$$Z_{dr}^{m} = \frac{P_H C_H^T W_H^2 (G_H^A)^2 C_H^R G_H^R \left\langle \left| S_{HH} \right|^2 \right\rangle}{P_V C_V^T W_V^2 (G_V^A)^2 C_V^R G_V^R \left\langle \left| S_{VV} \right|^2 \right\rangle}$$

Bias

$$\frac{R_{VHVH}}{R_{HVHV}} = \frac{P_H C_H^T C_V^R G_V^R \left\langle \left| S_{VH} \right|^2 \right\rangle}{P_V C_V^T C_H^R G_H^R \left\langle \left| S_{HV} \right|^2 \right\rangle}$$

$$S = \frac{W_V G_V^A C_V^R G_V^R}{W_H G_H^A C_H^R G_H^R}$$

Crosspolar powers

Sun measurement

CP Z_{dr} Calibration

Z_{dr} intrinsic

$$Z_{dr}^{m} = \frac{P_H C_H^T W_H^2 (G_H^A)^2 C_H^R G_H^R \left\langle \left| S_{HH} \right|^2 \right\rangle}{P_V C_V^T W_V^2 (G_V^A)^2 C_V^R G_V^R \left\langle \left| S_{VV} \right|^2 \right\rangle}$$

$$Z_{dr} = Z_{dr}^{m} S^2 \frac{R_{HVHV}}{R_{VHVH}} = \frac{\left\langle \left| S_{HH} \right|^2 \right\rangle}{\left\langle \left| S_{VV} \right|^2 \right\rangle}$$

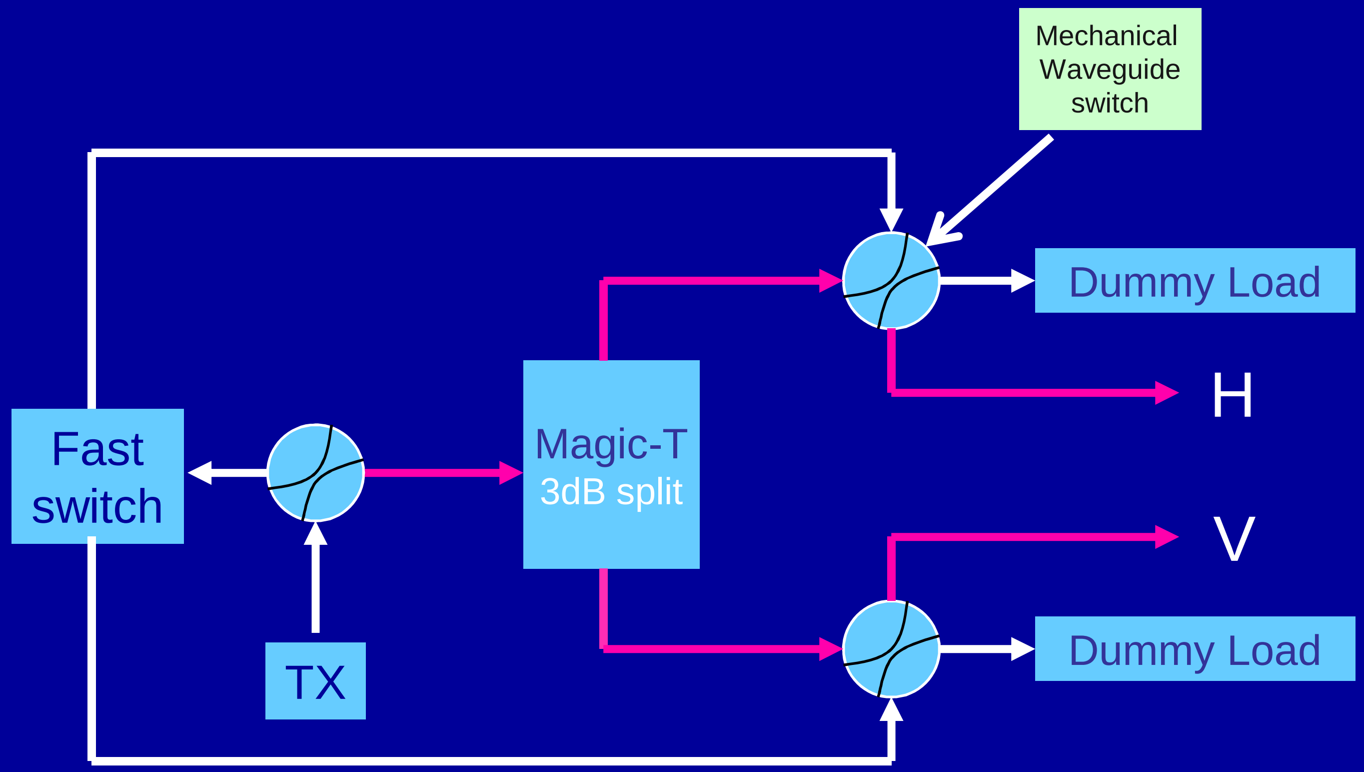
SHV Zdr Calibration for Simultaneous H and V Transmission

- E.g., WSR-88D is a simultaneous H and V transmit system
- Does that matter when doing Zdr calibration?
  - Yes! Must use crosspolar power targets that do not vary in time
  - i.e., ground clutter targets

Another Requirement

The electrical paths for S and R_{HVHV}, R_{VHVH} measurements are the same paths as the weather signals follow!

Front End for S-Pol

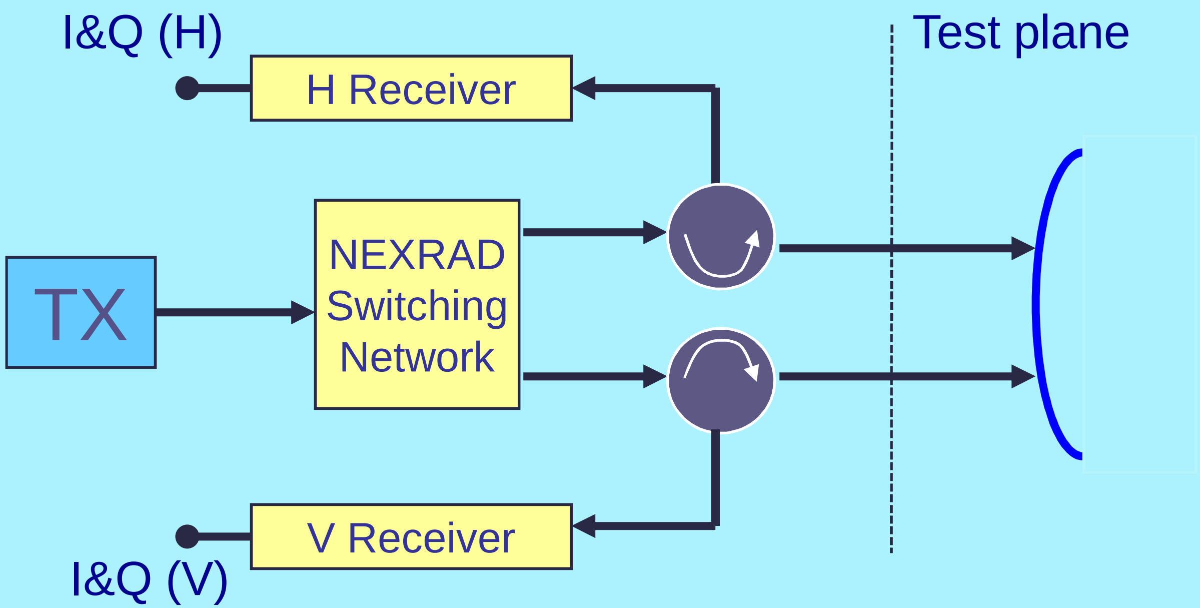


Advantage: Only H and only V paths are identical to simultaneous H/V paths.

$$P_H^S = P_H^{only} \qquad P_V^S = P_V^{only}$$

The is not true for NEXRAD!

WSR88-D Block Diagram



Problem:

$P_H^S \neq P_H^{only}$ $P_V^S \neq P_V^{only}$

Zdr Cal. For NEXRAD

$$Z_{dr}^{m} = \frac{P_H^{S} C_H^{T} W_H^{2} (G_H^{A})^{2} C_H^{R} G_H^{R} \left\langle \left| S_{HH} \right|^{2} \right\rangle}{P_V^{S} C_V^{T} W_V^{2} (G_V^{A})^{2} C_V^{R} G_V^{R} \left\langle \left| S_{VV} \right|^{2} \right\rangle}$$

$$\frac{R_{VHVH}}{R_{HVHV}} = \frac{P_H^{only} C_H^{T} C_V^{R} G_V^{R} \left\langle \left| S_{VH} \right|^{2} \right\rangle}{P_V^{only} C_V^{T} C_H^{R} G_H^{R} \left\langle \left| S_{HV} \right|^{2} \right\rangle}$$

Problem:

$P_H^{S} \neq P_H^{only}$ $\quad$ $P_V^{S} \neq P_V^{only}$

Zdr Cal. For NEXRAD

NEXRAD Bias term

$$Z_{dr}^{88D} = Z_{dr}^{m} S^{2} \frac{R_{HVHV}}{R_{VHVH}} = Z_{dr}^{Intrin.} \boxed{\frac{P_H^S \, P_V^{only}}{P_V^S \, P_H^{only}}}$$

- Thus we need to measure these transmit powers!
- But measurements can introduce additional uncertainty

Zdr Cal. For NEXRAD

$$M = \frac{P_H^{only}}{P_H^{S}} \qquad N = \frac{P_V^{S}}{P_V^{only}}$$

Because since these are ratios,
the uncertainties of the power measurements cancel

$$Z_{dr,cal}^{88D} = Z_{dr}^{m} S^2 \frac{R_{HVHV}}{R_{VHVH}} \, MN$$

Calibration Measurements

1. Scan the sun passively
   - 3 box scans about 7 deg. by 3 deg.
   - Integrate over ~1 deg. solid angle
2. ~Ten low level PPI scans for crosspolar powers
   - Alternate H and V transmit on a PPI by PPI basis
   - Watch for receiver saturation!
   - Use indexed beams!!
3. Monitor the 4 transmit powers
4. Monitor the H and V receiver paths (from LNAs to I&Q) by injecting test signals (for calibration maintenance)

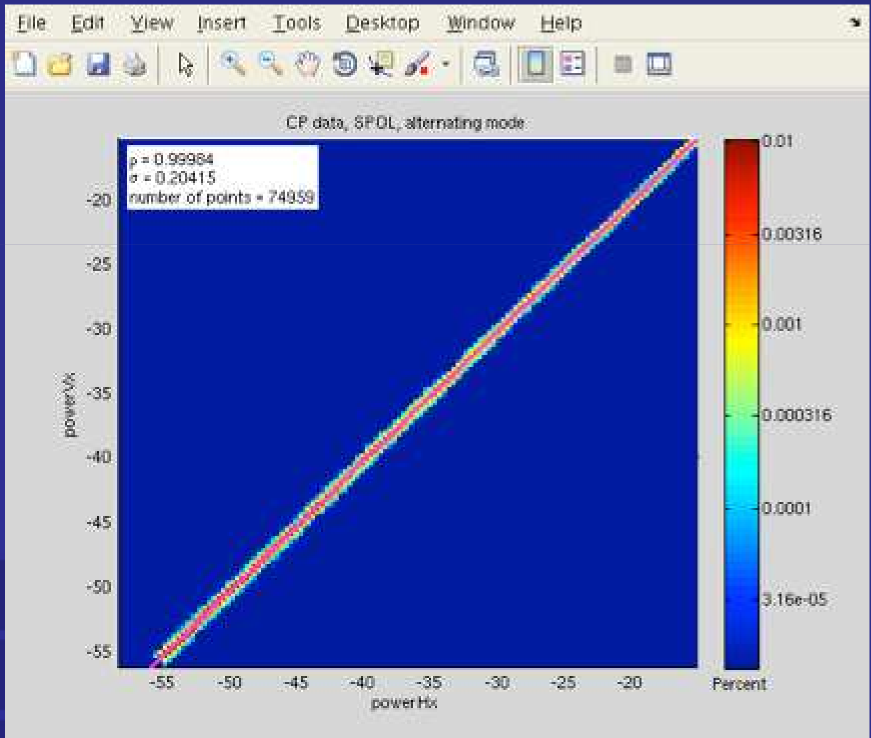
Calibration versus Calibration Monitoring

- The gains of the receiver paths will likely vary as a function of time, as will the transmit powers.
- Need to monitor this variation and correct for it.
- Continue to monitor the 2 transmit powers $P_{H,}^{S_t}$ $P_{V}^{S_t}$
- Continue to monitor the H and V receiver paths (from LNAs to I&Q) by injecting test signals

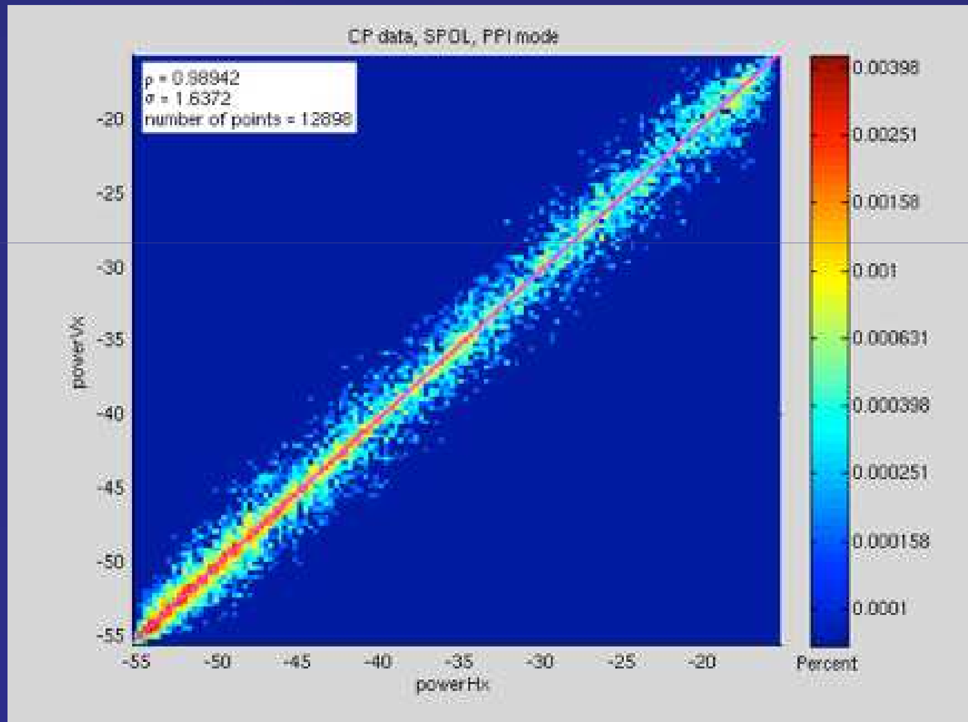
For example, calculate $P_H^{S_t} / P_H^{S_0}$ and adjust Zdr accordingly, dynamically .

S-Pol Crosspolar Power Histograms

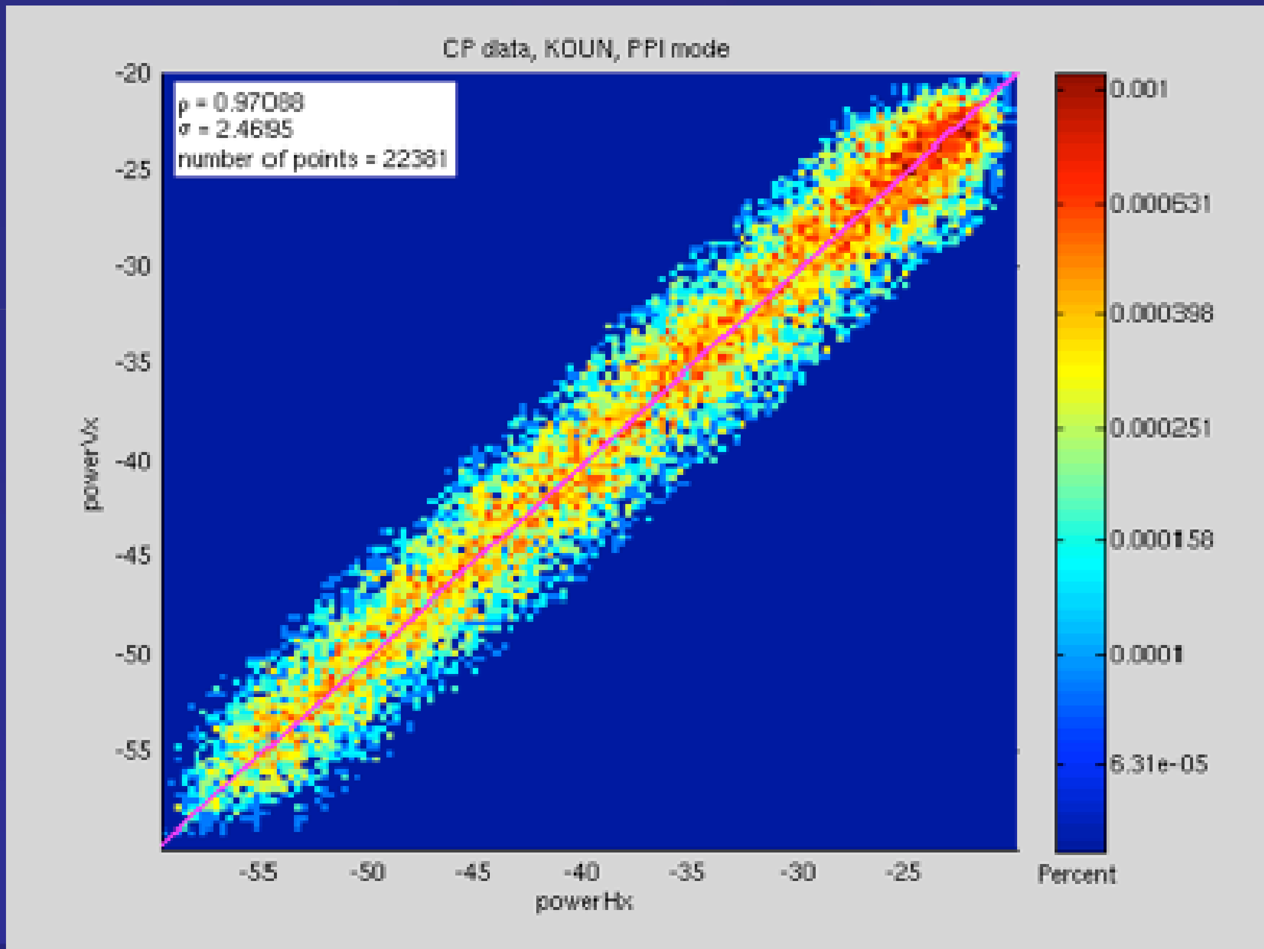
Fast alternating H and V pairs



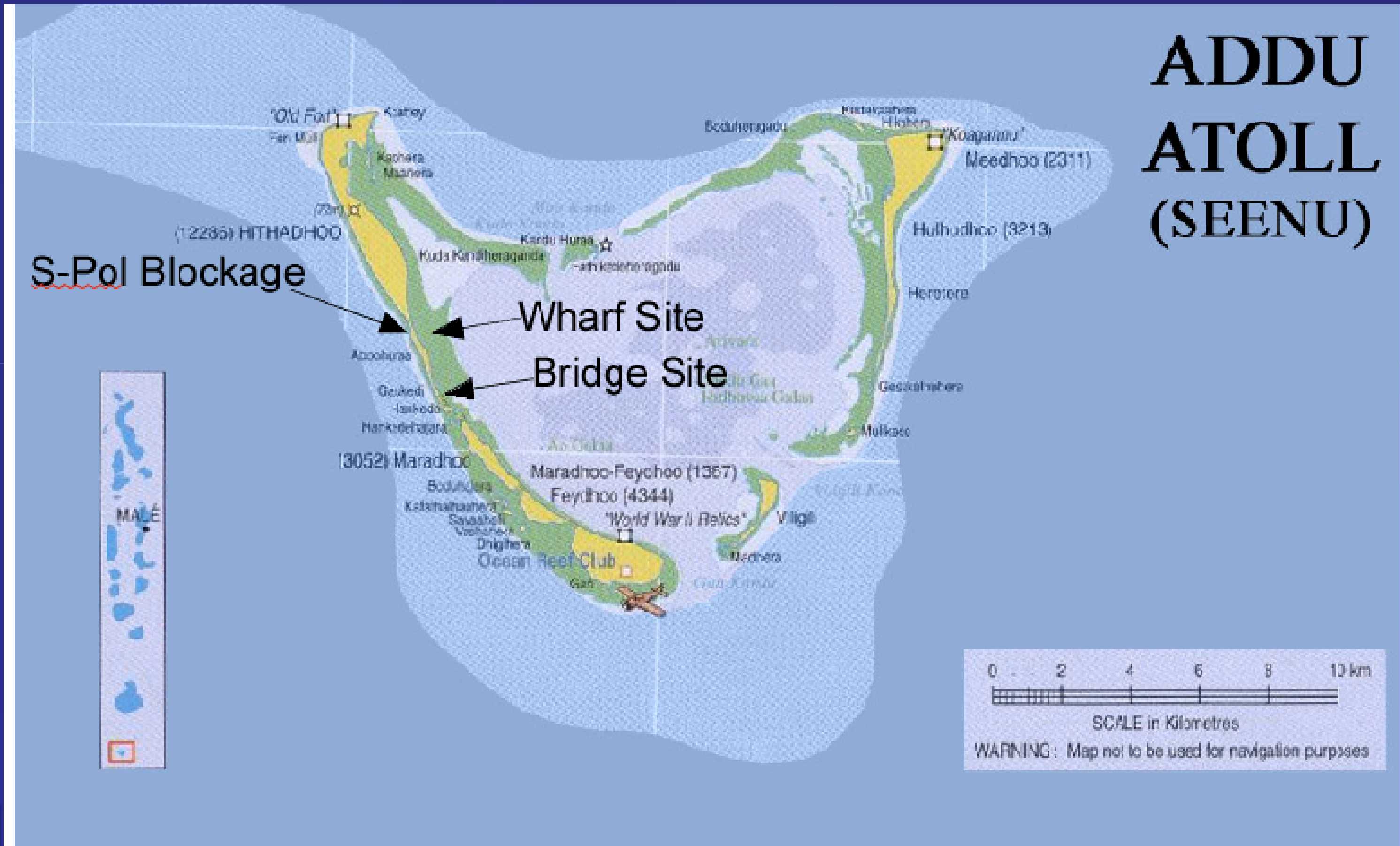
Alternate PPI H and V pairs



KOUN Crosspolar Power Histogram



S-Pol at DYNAMO in the Idian Ocean, Maldives



CP/VP Results from DYNAMO

Date	S1S2	Hx/Vx bias	CP Zdr bias	Vert (dB)	ZDR Error
====	====	=====	====	====	=====
2011/09/25	-0.300	-0.001	-0.299		
2011/09/28	-0.298	-0.004	-0.302		
2011/09/29	-0.232	-0.010	-0.242		
2011/10/05	-0.268	-0.047	-0.315	- 0.284	0.031
2011/10/10	-0.237	-0.036	-0.273	- 0.291	0.018
2011/10/23	-0.296	-0.023	-0.319	-0.307	0.012
2011/12/05	-0.278	-0.020	-0.298		
2011/12/09	-0.279	-0.019	-0.298	- 0.304	0.006
2011/12/15	-0.271	-0.020	-0.290		
2011/12/18	-0.369	0.009	-0.360		
2011/12/25	-0.196	0.008	-0.188		
2012/01/02	-0.279	-0.011	-0.280		
2012/01/14	-0.336	0.022	-0.314	-0.327	0.013
2012/01/16	-0.390	0.055	-0.340		

CP/VP Results from DYNAMO

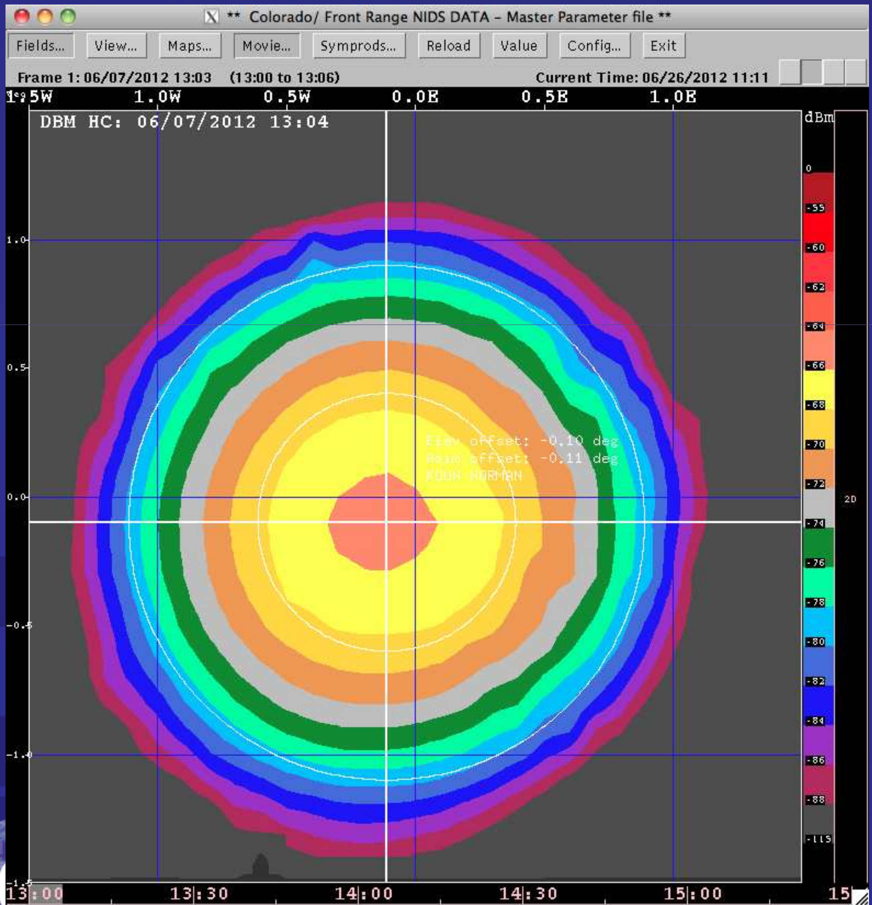
Below are the results of computing the CP-derived Zdr bias for various tilt angles, on 8 Jan. 2012. S-Pol was running volume scans on this clear day.

Elevation	Alt CP	PPI CP	Error (dB)
0.5 deg	-0.022	0.005	0.027
1.5 deg	-0.001	0.011	0.012
2.5 deg	0.002	0.009	0.007
3.5 deg	0.002	-0.016	-0.018
5.0 deg	0.001	0.016	0.015

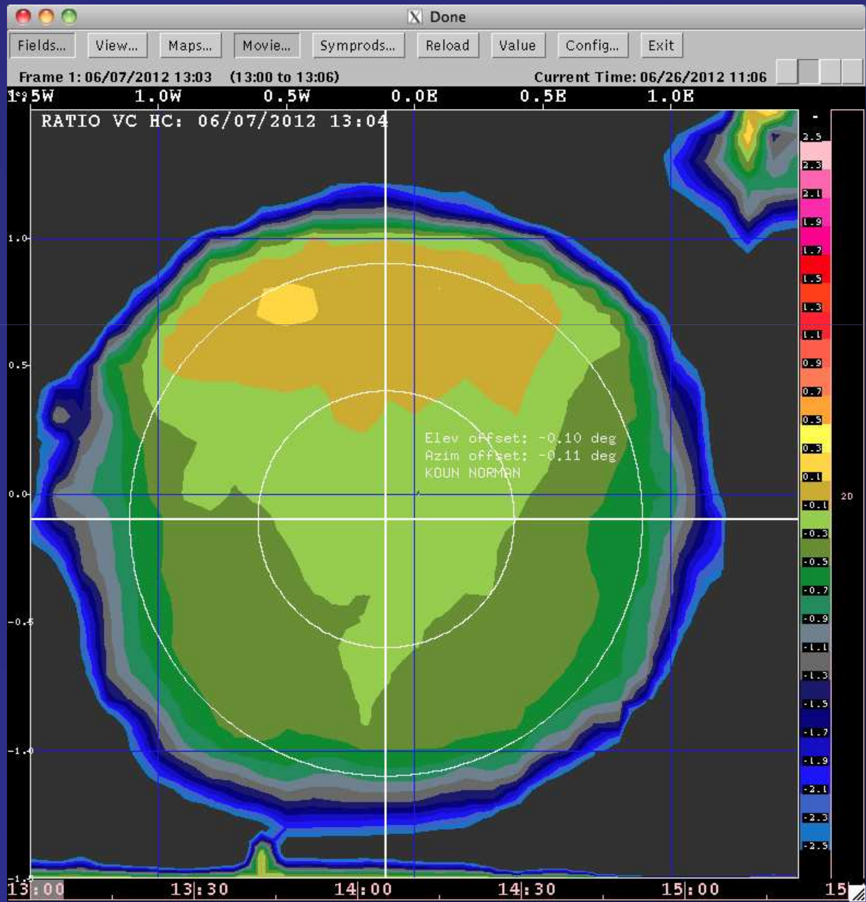
The mean squared error estimate is 0.017 dB.

KOUN Sun Scan Data

H antenna pattern

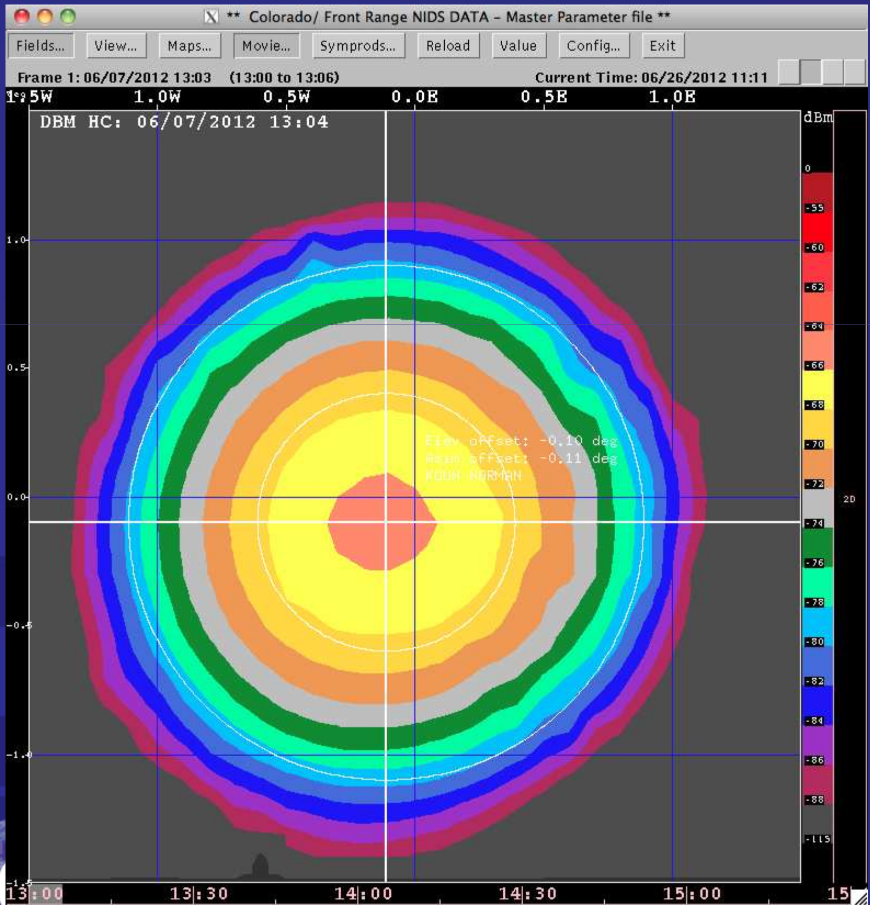


Zdr antenna pattern

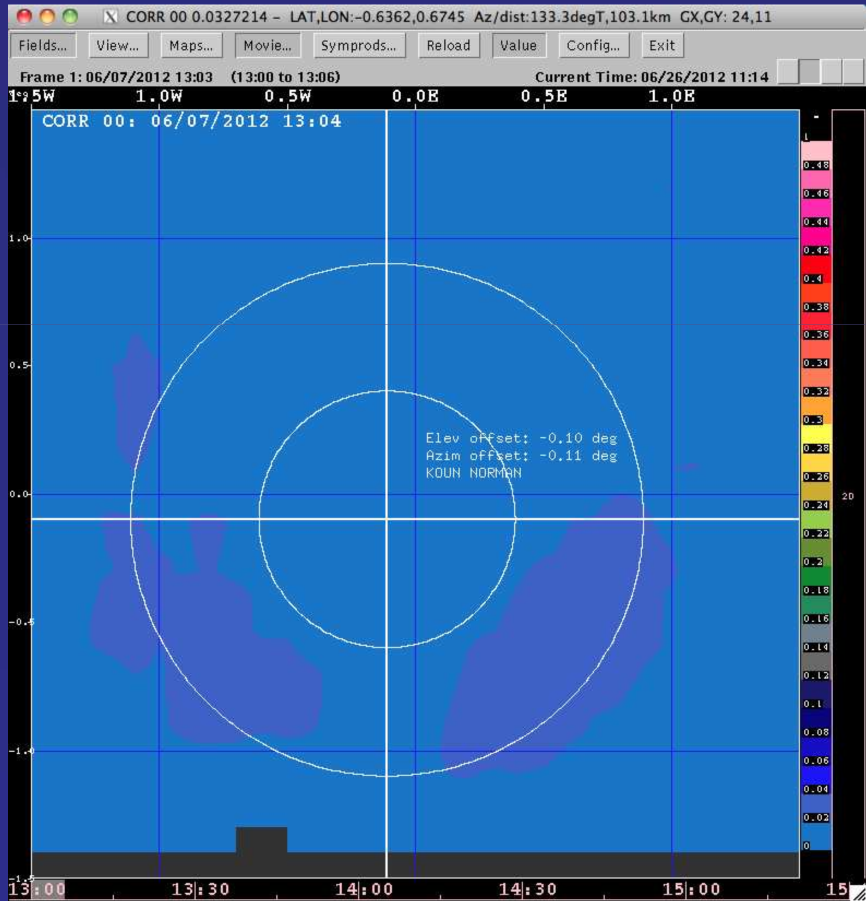


KOUN Sun Scan Data

H antenna pattern



H to V correlation antenna pattern



KOUN Calibration Data

From 7 June 2012

Time	Sun Sh/Sv	Xpol Pow. CPv/CPh	Receiver RXv/RXh	Tx Pow. TXv/TXh	Zdr bias
12:39	0.445	0.084	-0.430	-0.092	0.007
13:04	0.459	0.119	-0.439	-0.092	0.050
13:29	0.423	0.103	-0.435	-0.092	0.003
13:44	0.444	0.146	-0.429	-0.092	0.068

There are some calibration sets that are not so well behaved!
These measurements need to be done over several days to establish the uncertainty

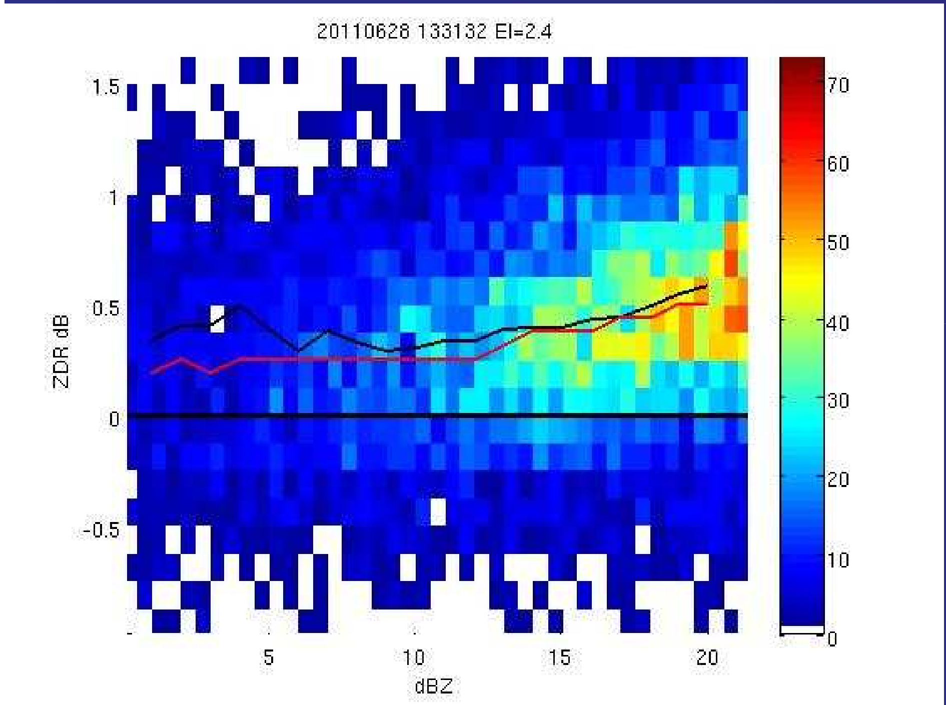
- But how can we cross-check the CP calibration figure??

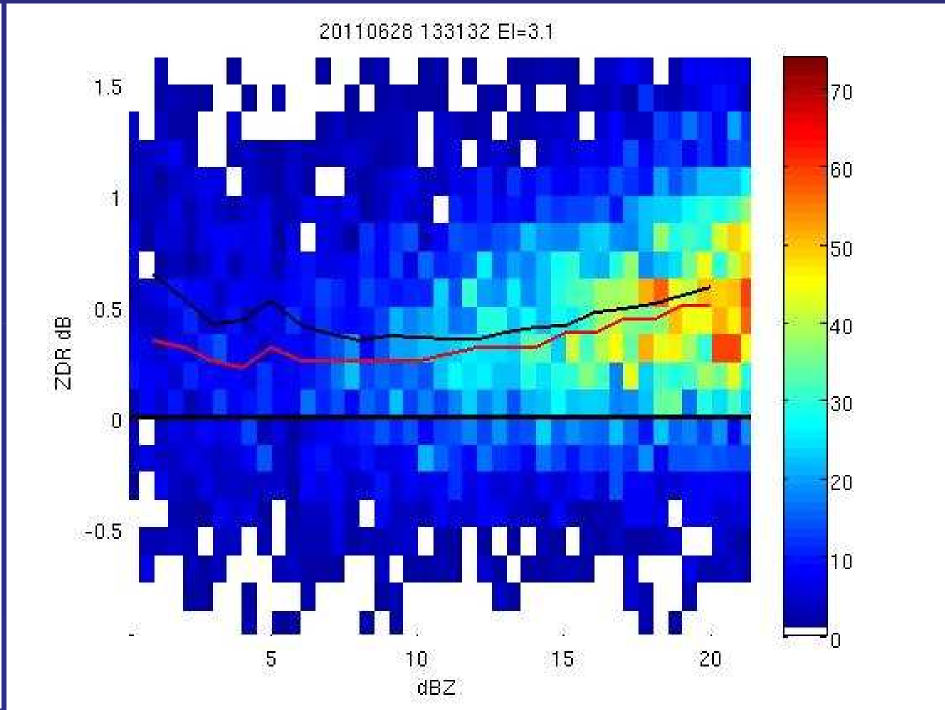
Zdr versus Z Histograms

Zdr calibration check

2.4 deg. elevation

3.1 deg. elevation





At ~20dBZ, Zdr~=0.25dB

At <10dBZ, Zdr~=0 dB

From histograms, mean Zdr = 0.58dB
Zdr bias:0.58 - 0.25 = 0.33dB

Summary

- The CP Zdr calibration technique has been shown to compare very well with the VP technique on S-Pol
- The transmitter topology of WSR-88Ds presents a further challenge for the CP technique
  - Need to measure the transmit power
- Testing CP on KOUN is ongoing. More data sets need to be gathered not only with KOUN but several other WSR-88Ds as well

Thank You
for Your Attention

Questions?

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"The basic calibration process is a difficult and expensive challenge. The cost for ordinary equipment support is generally about 10% of the original purchase price on a yearly basis, as a commonly accepted rule of thumb."

"The extent of the calibration program exposes the core beliefs of the organization involved."