INTRODUCTION TO DUAL-POL WEATHER RADARS

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Monash University, Australia
BEFORE STARTING

Every Radar is polarimetric because of the polarimetry of the electromagnetic waves BUT not every radar is **Dual-Pol** !!

Dual-Pol: T/R Horizontal and Vertical polarization waves
CONTENT

• Why Dual-Pol

• Brief description

• Limitations
SINGLE-POL VS DUAL-POL

VS
IF YOU DON'T USE IT CORRECTLY!
The radar equation: \( P_r = \frac{\pi^3}{1024 \ln(2)} \cdot \frac{P_i G^2 \phi \tau}{\lambda^2} \cdot \frac{1}{R^2} \cdot |K|^2 Z \)

System constant, (remote sensing constant)

Range dependent

Target characteristics and attenuation
BUT WHAT IF YOU ...

Get a better calibration

Know better what is going on the way

Know better the targets

\[ P_r = \frac{a^2}{1024 \lambda^2} P_i G^2 \Theta \phi \tau \cdot \frac{1}{R^2} \]

System constant, (remote sensing constant)

Range dependent

Target characteristics and attenuation
RADAR EQUATION

Radar Reflectivity

Depends on:

• size (particle diameter)
• concentration (number of particles per unit volume)
• state (frozen, liquid or mixture)
• shape (round, oblate, flat)

Most important – size and state
DUAL-POL – KEY BENEFITS

Hydrometeor Quantification:

• Attenuation Correction
• Precipitation Estimation

Hydrometeor Classification:

• Discrimination of Non-Meteorological Targets
• Hydrometeor Classification

Improvement in radar data quality: Calibration
Horizontally (blue) and vertically (red) polarized pulse, emitted by a dual-polarization radar (lower left)

(Pruppacher and Klett, 1997)
DUAL-POL – ZDR

Differential Reflectivity (ZDR):

• Ratio of power returned at H and V polarization

• **Dependent** on the **shape** of hydrometeors, as well as their **density** and **composition**

• **Independent** of hydrometeor **concentration**

• Affected by differential attenuation, anisotropic beam blockage, noise bias, depolarization, and non-uniform beam filling

ZDR can be used to distinguish between liquid and ice phases of water as well as to identify echoes from non-meteorological targets

\[
Z_{DR} = 10 \log \left( \frac{Z_h}{Z_v} \right)
\]
Increased wobbling (i.e., increased distribution of canting angles within a radar sampling volume) leads to decreased ZDR.

 Totally chaotic orientation leads to ZDR = 0 dB

 The behavior of ZDR becomes complicated for resonance (Mie) scatterers, i.e. when the size of the particle becomes comparable or bigger than the radar wavelength (D ~> λ).
DUAL-POL – ΦDP

Differential Phase Shift

ΦDP is the phase shift between the H and V polarized waves. The shift results from different propagation times of H and V polarized radiation.

H_\text{i} and V_\text{i} are the complex voltage (I+jQ) samples received on the H and V channels.

$$\Phi_{\text{DP}} = \arg\left[\frac{1}{N} \sum_{i=1}^{N} V_i H_i^*\right]$$

$$\Phi_{\text{DP}} = \Phi_H - \Phi_V$$
DUAL-POL – ΦDP

Courtesy to Matt Kumjiam
DUAL-POL – KDP

Specific Differential Phase Shift

KDP is half the range derivative of $\Phi_{DP}$. In other words, it is the amount of phase shift accumulated per unit distance (per km).

KDP is much stronger correlated to the rain rate than is Z or ZDR; and furthermore it is $\sim$ independent of attenuation and partial beam blocking.

$$KDP \approx \frac{1}{2} \frac{\Delta \Phi_{DP}}{\Delta r}$$
DUAL-POL – KDP

• KDP is dependent on particle concentration and size, as well as their composition.

• Because it is a phase measurement, it is immune to radar miscalibration, attenuation and differential attenuation, partial beam blockage, and is not biased by noise.

• KDP is difficult to estimate in regions of low SNR (and/or low $\rho_{hv}$), and is prone to errors in the presence of non-uniform beam filling and backscatter differential phase.

• KDP values are:
  • Low with noise for snow and light rain
  • High in oriented crystals
  • Increase with the increasing of oblateness, water content and density
  • ~ 0 for spherical or randomly oriented particles.
DUAL-POL – PROCESSING $\Phi$DP AND KDP

Data of the $\Phi_{DP}$ have to be filtered before deriving KDP

Filtering Steps:
- $\Phi_{DP}$ unwrapping (180°- or 360°-de-aliasing)
- Bad data thresholding: SNR, $\sigma(\Phi_{DP})$
- Data smoothing or iterative filtering

Several Smoothing methods are possible:
- Moving average (weighted or non-weighted)
- Median filter
- Finite impulse response (FIR) filter
DUAL-POL – PROCESSING $\Phi_{DP}$ AND $K_{DP}$
Correlation Coefficient

$\rho_{hv}$ provides the complex correlation between H and V polarized signals.

$$|\rho_{hv}| = \sqrt{\frac{H_i^*V_i}{N_h \sum_{i=1}^{N}|H_i|^2 - N_h \sum_{i=1}^{N}|V_i|^2}}$$

It is a measure of the variability of the scattering properties within the radar sampling volume.

In other words: The variability of certain physical properties of hydrometeors causes a reduction of $\rho_{hv}$.

Relevant physical properties are those that affect the backscattered amplitude and phase at H- and V- polarization, i.e., particle shape, orientation angle, and composition.
DUAL-POL – RHOHV

- Independent of hydrometeor concentration
- Immune to attenuation and differential attenuation, radar miscalibration, and signal depolarization
- Can be biased by low S/N, and in the presence of non-uniform beam filling.
- Close to 1.0 in pure rain, pure aggregated snow, pure graupel, etc.
- Lowered in a mixture of rain and snow, rain and hail, and in the presence of Mie scattering (e.g., large wet hail).
- Anomalously low in non-meteorological targets.
Linear Depolarization Ratio

LDR is the ratio between V and H polarized reflectivity for a H polarized transmitter pulse, in other words: the ratio of the cross-polarized reflectivity to the co-polarized reflectivity.

Typical LDR values are:
- Snow: LDR < -25 dB
- Wet Snow: LDR ~ -15 dB
- Rain: LDR < -25 dB
- Hail: -25 < LDR < -15 dB

\[ LDR = 10 \log \left( \frac{\sum_{i=1}^{N} |V_i \text{Crosspol}|^2 - N_v}{\sum_{i=1}^{N} |H_i \text{Copol}|^2 - N_h} \right) \]
LIMITATIONS

• Calibration

• Most of algorithms are only for Rain

• More expensive

• Less transmitting power
And if you are really curious to know how old I am

I´m ...

1+1+1+1+1+1+
1+1+1+2+1+1+1+
1+1+1+1+1+1+
1+1+1+1+1+1+
1+4+1+1+1

Years Old
Now ok …
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LDR – X- BAND

• LDR is highly correlated with RhoHV, which is routinely available scan. This means that the additional benefit of LDR is small.

• One problem with LDR is the generally low SNR of the cross-polar returns. For example if the co-polar sensitivity is -5 dBZ at 60 km, then a true LDR of -30 dB at that range can only be detected if the Z > 25 dBZ. Hence a strong co-polal signal is needed. Opposed to that, RhoHV can be measured reliably at low SNR, i.e. at much lower reflectivity than LDR. Furthermore LDR must be corrected for noise.

• At X-band frequencies the LDR is affected significantly by DPATC in rain, which isn't the case for RhoHV.

• LDR is useful only for quite high SNR, but not for very high Z due to DPATC. This puts a limit to its utility in an operational setting.