Backscatter differential phase - estimation and variability.

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Hier können dann die Logos der Forschungseinrichtungen platziert werden.
Outline

1. Introduction

2. δ in rain
   – Estimation of δ
   – DSD analysis with respect to Z_{DR}-δ-relation

3. δ within the melting layer
   – Estimation of δ
   – The impact of non-uniform beam filling
   – Variability of δ at X, C, and S-bands

4. Conclusions
Introduction

The measured total differential phase $\Phi_{DP}$ shift consists of the 2 components:

$$\Phi_{DP} = \delta + 2 \int_0^K K_{DP}(s) dS = \delta + \varphi_{DP}$$

where

- $\Phi_{DP}$ = total differential phase,
- $\varphi_{DP}$ = differential propagation phase,
- $K_{DP}$ = specific differential phase,
- $\delta$ = backscatter differential phase.

For accurate rainfall estimation using $K_{DP}$ backscattered and propagation components of $\Phi_{DP}$ need to be separated before specific differential phase $K_{DP}$ is estimated from the range derivative of $\Phi_{DP}$.

Perturbations of the $\Phi_{DP}$ profile through the melting layer can be attributed either to $\delta$ or effects of nonuniform beam filling (NBF).

Benefits of using $\delta$ is its direct relation to the prevalent size of hydrometeors:

- $\delta$ can be used for more accurate retrieval of hydrometeor size distributions
- $\delta$ should be generally correlated with $Z_{DR}$, can serve as a proxy for $Z_{DR}$
Backscatter differential phase $\delta$ of raindrops

Fig. Simulated $\delta$ as a function of equivolume raindrop diameter for different wavelengths and temperatures.

$\delta$ in rain depends on $\lambda$ and $T$ and increases with raindrop size.
Estimation of $\delta$ in rain

Application of the ZPHI-method (Testud et al., 2000) and the slightly modified self-consistent method proposed by Bringi et al. (2001):

- **External constraint:** $\Delta \phi_{DP} = \phi_{DP}(r_2) - \phi_{DP}(r_1)$ with ranges $r_1$ and $r_2$ from the radar

- **2 relationships** $A_h = \beta Z_h^b$ and $A_h = \alpha K_{DP}$ with $\beta$, $\alpha = fkt(\text{drop shape, } T)$

$$A_h(r) = \frac{[Z_a(r)]^b f(\Delta \phi_{DP})}{I(r_1; r_2) + f(\Delta(\phi_{DP}))I(r; r_2)}$$

where

$$I(r; r_2) = 0.46b \int_{r}^{r_2} [Z_a(s)]^b ds,$$

$$I(r_1; r_2) = 0.46b \int_{r_1}^{r_2} [Z_a(s)]^b ds,$$

$$f(\Delta \phi_{DP}) = 10^{0.1ab\Delta \phi_{DP}} - 1$$

The selfconsistent method (Bringi et al., 2001), slightly modified, searches for optimal $\alpha$ and $b$ by comparing calculated and measured $\Phi_{DP}$:

$$\min_{\alpha, b} \Delta \phi = \sum_{i=1}^{N} |\varphi_{DP}^{cal}(r_i; \alpha; b) - \Phi_{DP}(r_i)|$$

where

$$\varphi_{DP}^{cal}(r, \alpha; b) = 2\int_{r_1}^{r} \frac{A(s; \alpha; b)}{a} ds$$
Estimation of $\delta$ in rain

Application of the ZPHI-method (Testud et al., 2000) and the slightly modified self-consistent method proposed by Bringi et al. (2001).

Differences between $\Phi_{DP}$ and $\Phi_{cal}^{DP}$ calculated via the ZPHI-method reveal statistical fluctuations and $\delta$.

$\rho_{HV}>0.9$ is used as criterion for separating $\delta$ perturbations and the ones caused by noise.

Pro: Method provides reasonably robust estimates of $\delta$ and $K_{DP}$ in pure rain outside areas affected by NBF or low S/N ratios. Spatial and temporal coherency of retrieved $\delta$ can be demonstrated.

Con: Less suitable for areas with high $K_{DP}$.

Fig: PPIs of $\delta$ for the BoXPo1 observations on June 22, 2011 between 11:11 UTC and 11:26 UTC.
Reliability of the method for $\delta$ detection

Example: PPIs of $\delta$ for the BoXPoI observations on June 22 between 11:11 UTC and 11:26 UTC.

Pro:
- Spatial and temporal coherency of retrieved $\delta$ can be demonstrated.

Con:
- Less suitable for areas with high $K_{DP}$.
Z\textsubscript{DR}-δ relationships

Simulations for X-band based on...

2D Video measurements in Oklahoma, USA

- at 0°C
- at 30°C
- δ = Z\textsubscript{DR}^{1.8}

Parsivel measurements in Bonn, Germany

- at 15°C
- δ = Z\textsubscript{DR}^{1.8}

The overwhelming part of variability can be related to the temperature of raindrops.
The impact of differences in DSDs seems to be small.
Backscatter differential phase $\delta$ - another parameter for characterizing dropsizes -

Simulations for X-band at 15 °C based on..

2DVideo measurements in Oklahoma, USA

Parsivel measurements in Bonn, Germany
Backscatter differential phase $\delta$ in the melting layer

Observed bumps in differential phase $\Phi_{DP}$ may be associated either with

1. backscatter differential phase $\delta$
2. nonuniform beamfilling (NBF):

$$\Delta \Phi_{DP} = 0.02 \Omega^2 \frac{d\Phi_{DP}}{d\theta} \frac{dZ}{d\theta}$$  
(Ryzhkov et al., 2007)

Method for reliable $\delta$-estimation in the melting layer:

- Calculate azimuthally averaged radial profiles of $\Phi_{DP}$ from measurements at higher elevation angles
- forward propagation contribution is minimized
- suppress fluctuations of $\Phi_{DP}$ caused by reduction of $\rho_{HV}$ within the melting layer,
- impact of NBF is minimized
Backscatter differential phase $\delta$ in the melting layer

Observed bumps in differential phase $\Phi_{DP}$ may be associated either with

1. backscatter differential phase $\delta$

2. nonuniform beamfilling (NBF) $\Delta \Phi_{DP} = 0.02 \Omega^2 \frac{d\Phi_{DP}}{d\theta} \frac{dZ}{d\theta}$ (Ryzhkov et al., 2007)

Method for reliable $\delta$-estimation in the melting layer:

Fig. Azimuthally averaged quasi-vertical profiles from the polarimetric X-band radar in Bonn (BoXPol), Germany, obtained on 04 December 2011, at 20:51 UTC, from the PPI at elevation 7°.
Backscatter differential phase $\delta$ in the melting layer

Observed bumps in differential phase $\Phi_{DP}$ may be associated either with

1. backscatter differential phase $\delta$ \hspace{1cm} $\delta_{obs,X} = 3^\circ$

2. nonuniform beamfilling (NBF) \hspace{1cm} $\Delta \Phi_{DP} = 0.11^\circ$

Method for reliable $\delta$-estimation in the melting layer:

Fig. Azimuthally averaged quasi-vertical profiles from the polarimetric X-band radar in Bonn (BoXPoI), Germany, obtained on 04 December 2011, at 20:51 UTC, from the PPI at elevation 7°.
Variability of $\delta$ within the melting layer at X, C, and S bands

-Observations at X-band (BoXPol), $\delta_{\text{obs},X} \approx 7^\circ$

Fig. Magnitudes of the extremes of $Z_{\text{DR}}$, $\rho_{\text{HV}}$, and $\delta$ in the melting layer observed with BoXPol at 7° elevation on December 04, 2011 between 19:36 UTC and 22:29 UTC.
Variability of $\delta$ within the melting layer at X, C, and S bands

- Observations at X-band (BoXPol), $\delta_{\text{obs},X} \approx 7^\circ$

Fig. Relative heights of the extremes of $Z_{DR}$, $\rho_{HV}$, and $\delta$ in the melting layer observed with BoXPol at $7^\circ$ elevation on December 04, 2011 between 19:36 UTC and 22:29 UTC.
Variability of $\delta$ within the melting layer at X, C, and S bands

- Simulations -

Fig. Simulated vertical profiles of $Z$, $Z_{\text{DR}}$, and $\delta$ within the melting layer at S, C, and X bands. Freezing level is at 1 km, temperature lapse rate is 6.5 °/km, relative humidity is 100%, and rain rate near the surface is 5 mm/h.
Variability of $\delta$ within the melting layer at X, C, and S bands

-Observations at X-band (JuXPol), $\delta_{\text{obs},X} \approx 7.5^\circ$

**Fig:** Azimuthally averaged quasi-vertical profiles from the polarimetric X-band radar in Jülich (JuXPol), Germany, obtained on 24 September 2010, at 4:50 UTC, from the PPI at elevation 37°.
Variability of $\delta$ within the melting layer at X, C, and S bands

- Observations at C-band (OU-PRIME), $\delta_{\text{obs,C}} \approx 6^\circ$

Fig: Azimuthally averaged quasi-vertical profiles from the C-band University of Oklahoma Polarimetric Radar in Meteorology and Engineering (OU-PRIME), USA, obtained on 24 December 2009, at 16:41 UTC, from the PPI at elevation 10°.
Variability of $\delta$ within the melting layer at X, C, and S bands

- Observations at S-band (KATX), $\delta_{\text{obs},S} \approx 5.5^\circ$

Fig: Azimuthally averaged quasi-vertical profiles from the KATX polarimetric WSR-88D S-band radar near Seattle, Washington, USA, obtained on 18 February 2012, at 00:59 UTC, from the PPI at elevation 7.5°.
Conclusions

- New methods for estimating $\delta$ in rain and in the melting layer have been suggested.

1. Estimating $\delta$ in rain is based on the ZPHI method and provides reasonably robust estimates of $\delta$ and $K_{DP}$ in pure rain.
   → Relevant for quantitative precipitation estimation, especially at X band

2. Reliable estimates of $\delta$ within the melting layer of stratiform precipitation can be obtained via azimuthal averaging of radial profiles of $\Phi_{DP}$ at high antenna elevations.
   → Method enables to examine microphysical properties of the melting layer and likely to estimate maximal size of melting snowflakes.

- Large disdrometer datasets collected in Oklahoma and Germany confirm a strong interdependence between backscatter differential phase $\delta$ and differential reflectivity $Z_{DR}$.
   → $\delta$ and $Z_{DR}$ are differently affected by particle size spectra and can complement each other for particle size distribution (PSD) retrievals.
Thank you!

Trömel, S., Kumjian, M., Ryzhkov, A., Simmer, C.: Backscatter differential phase - estimation and variability. To be submitted next week to JAMC.