THE MEASUREMENTS OF BACKSCATTER DIFFERENTIAL PHASE δ

IN THE MELTING LAYER AT X AND S BANDS

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1. INTRODUCTION

The polarimetric variable backscatter differential phase δ is defined as the difference between the phases of horizontally and vertically polarized components of the wave caused by backscattering from objects within the radar resolution volume.

δ (measured in [°]) contributes to the total measured differential phase Φ_{DP} [°], along with the propagation differential phase φ_{DP} [°]. It has been recognized that accurate rainfall measurements using K_{DP} (particularly at X band) are contingent on the effectiveness of a separation of the backscattered and propagation components of Φ_{DP} (e.g., Matrosov et al. 1999, 2002; Otto and Russchenberg 2011; Schneebeli and Berne 2012). However, the practical utilization of the backscatter differential phase δ is not well explored yet.

δ is a tell sign for Mie scatterers in the radar volume and bears important information about the dominant size of drops in rain and of wet snowflakes in the melting layer. A relation between δ and Z_{DR} - the differential reflectivity (difference between reflectivities of the horizontally and vertically polarized wave components) - in rain has been noted. For example, Otto and Russchenberg (2011) suggested a best-fit relationship

$$\delta = Z_{DR}^{1.8} \qquad (1)$$

with δ in [°] and Z_{DR} in [dB] based on scattering computations at X band. Schneebeli and Berne (2012) confirm these findings, come up with a similar best-fit power law

$$\delta = 0.632 Z_{DR}^{1.71} \qquad (2)$$

and attribute the difference between the two Z_{DR}-δ relations to temperature effects. Trömel et al (2013) demonstrate the temperature impact on the Z_{DR}-δ relationship based on distrometer data sets in Oklahoma, US, and Bonn, Germany. They found the overwhelming part of the variability unexplained by Z_{DR} related to raindrop temperature variation, while the impact of differences in DSDs typical for Oklahoma and Bonn, seems to be of secondary importance. Berenguer and Zawadzki (2009) report clear correlations between bright band intensity and Z_{DR} near the surface, which hints at big melting snowflakes creating big raindrops. These findings suggest, that δ and Z_{DR} measurements and the analysis of their relationship in the melting layer (ML) may open a new avenue to better Z-R-relationships for utilization near the ground. For example, in rimed snow, Z_{DR} and δ are lower (both in the ML and in the rain below) while the rain rate is higher for a given reflectivity Z_H in the rain below when compared to cases with non-rimed snow in the ML (e.g., Ryzhkov et al. 2008). In object-based approaches to precipitation system analysis from the Lagrangian perspective (Trömel et al. 2009, Trömel and Simmer 2012), up to now solely reflectivity-derived descriptors are used to characterize the intensity of the brightband. Since the new polarimetric variable δ is an indicator for the dominant size of rain drops or wet snowflakes and thus microphysical processes, the quantification of δ and other polarimetric variables in the ML will allow to better characterize the brightband and the temporal evolution of the system which can be exploited for both improving microphysical models of the ML and quantitative rainfall estimation. Thus, analyses of δ, together with horizontal reflectivity Z_H, differential reflectivity Z_{DR}, and cross-correlation coefficient ρ_{hv} within the ML measured at X band in Germany and at S band in U.S. have been performed to further explore its informative content for microphysical studies.

2. METHOD

Measured total differential phase Φ_{DP} routinely exhibits characteristic “bumps” also within the ML, which may be associated with either δ or with nonuniform beam filling (NBF). Within the ML ρ_{hv} can vary from 0.8 to 0.97 and statistical variations of Φ_{DP} may become so overwhelming that δ cannot be reliably measured on a radial basis. A reliable method for estimating δ in the ML has been published by Trömel et al. (2013): azimuthal averaging of Φ_{DP} data measured at high antenna elevations (>7°) suppress fluctuations of Φ_{DP} caused by low ρ_{hv} within the ML, which allows to better separate effects of δ and K_{DP} and minimize the impact of NBF. In cases of uniform stratiform precipitation averaging may extend over all azimuths prior to δ detection along the range. Values of Φ_{DP} just above and below the ML are connected with a straight line, and the difference between the actual average profile of Φ_{DP} along the range and the straight line is used to derive the maximal azimuthally averaged δ. For more heterogeneous precipitation fields only an azimuthal sector containing subjectively-identified uniform bright-band characteristics is averaged (see also Trömel et al., 2013, for an estimate of how much averaging is needed).

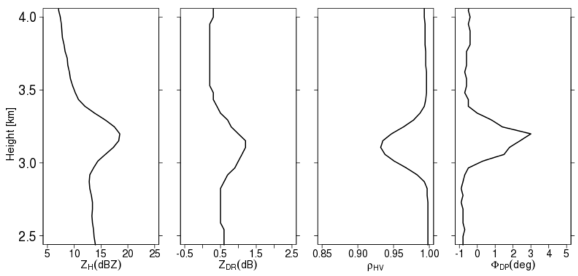

Figure 1: Quasi-vertical averaged profiles of Z_{DR}, ρ_{hv}. and δ in the ML observed with the BoXPol radar in Bonn, Germany, at 28° elevation on 20 June 2013.

Even though both δ and K_{DP} decrease with increasing elevation, the use of high elevation scans is beneficial to reduce the K_{DP}-related contribution to total differential phase Φ_{DP}. The forward propagation component of Φ_{DP} is proportional to the product of K_{DP} and slant propagation path within the ML, which decreases with elevation while δ is a local parameter and not an integral. Consequently, with increasing elevations the forward propagation contribution to Φ_{DP} is successively reduced with higher elevations leading to increasingly “clean” δ estimates without contamination from K_{DP}.

Additionally, NBF effects are smaller at higher elevations and become negligible compared to the magnitude of δ. This has been verified for the cases presented in the following section, where we estimate the NBF-induced bias of Φ_{DP} from the product of the vertical gradients of Z_H and Φ_{DP} according to Ryzhkov (2007).

3. OBSERVATIONS OF δ IN THE MELTING LAYER

a. δ MEASUREMENTS AT X BAND IN GERMANY

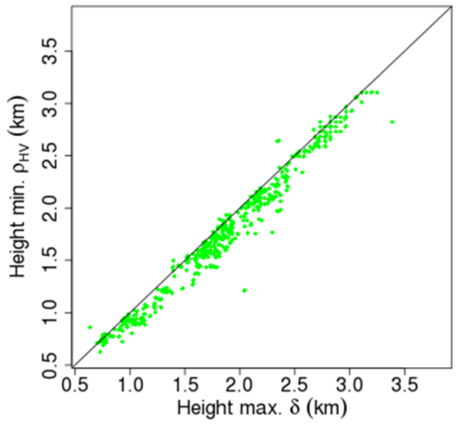

Figure 2: Relative heights of ρ_{hv} and δ in the ML observed with BoXPol and JuXPol.

480 snapshots for 13 different precipitation events in Germany observed with the polarimetric X band radars in Bonn (BoXPol) and Jülich (JuXPol) have been analyzed. The polarimetric X-band radar in Bonn (BoXPol), Germany, scans every 5 minutes at 28° elevation. Fig. 1 shows its azimuthally averaged profiles of Φ_{DP}, Z_{DR}, ρ_{hv}, and Z_H measured on 20 June 2013 at 21:40 UTC. The ML is clearly identified at around 3.2 km height, showing an increase of Z_H and Z_{DR} and a decrease of ρ_{hv}. The local increase of Φ_{DP} is now almost exclusively attributed to δ. According to the method described in Sec.2 the estimated magnitude of δ is 3.6°. The maximum δ value observed during all the events investigated in Germany is about 7.5°.

For all 480 events the relative heights of different polarimetric moments and their magnitudes in the ML have also been investigated. According to polarimetric theory of the melting layer the height level of the δ maximum is generally above the Z_{DR} maximum, which is also confirmed by our observations (see Fig.1). The theory, however, is not clear regarding the relative heights of the δ maximum and the ρ_{hv} minimum. The observations in Germany at X band depicted in Fig. 2 indicate that the height level of the δ maximum is above the ρ_{hv} minimum. The observations show also that the height level of maximum Z_H and δ are approximately at the same height (not shown here). These unexpected findings have to be further explored. In agreement with our expectations is, however, that the correlation between δ and ΔZ_H in the ML is not significant because δ does not depend on particle concentration. A strong correlation between δ and $\Delta\rho_{hv}$ is observed in only one case (4 December 2011, see Trömel et al., 2013), which is again somewhat unexpected.

b. δ MEASUREMENTS AT S BAND IN THE US

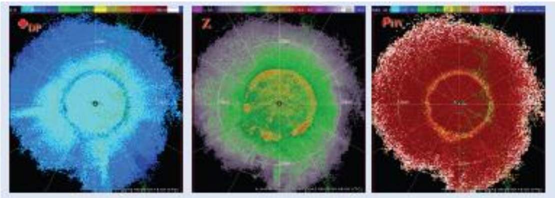

Figure 3: PPIs of Z_{DR}, ρhv, and δ in the ML observed with the KJAX radar in Jacksonville, Florida, at 9.9° elevation on 26 June 2012.

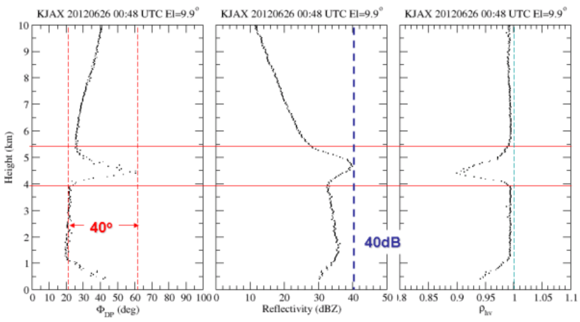

Figure 4: Quasi-vertical averaged profiles of Z_{DR}, ρ_{hv}, and δ in the ML observed with the KJAX radar in Jacksconville, Florida, at 9.9° elevation on 26 June 2012.

The data for 7 precipitation events observed with the WSR-88D S band radars in the US were analyzed. As an example Fig. 3 shows the PPIs of Z_{DR}, ρ_{hv}, and δ in the ML observed with the KJAX radar in Jacksonville, Florida, at 9.9° elevation on 26 June 2012. The brightband is quite pronounced across the entire azimuthal range and all variables shown (all 360^0 have been averaged in order to derive the quasi-vertical averaged profiles shown in Fig. 4). Again, a maximum value of azimuthally averaged δ along the range is estimated. Surprisingly, the magnitude of δ in the ML is about 40°. Furthermore, all days show well-pronounced δ estimates ranging from 18 to 40°. According to simulations of δ within the ML using the microphysical and scattering model for melting snow described by Giangrande (2007) and Ryzhkov et al. (2008), the simulated values of δ are relatively small and barely exceed 4° at X, C, and S bands. Indeed, the simulations assume that mixed-phase particles do not interact with each other and wet snowflakes do not aggregate. Taking aggregation into account in the model the magnitude of δ can be significantly higher. The huge observed δ magnitudes at S band ranging from 18 to 40°, however, are impressive and unexpected.

4. SUMMARY AND OUTLOOK

Backscatter differential phase δ within the ML is a reliably measurable parameter, which exhibits high variability. A method recently introduced for estimating δ in the melting layer has been applied to polarimetric radar observations at X band in Germany and S band in the U.S. Model simulations which assume spheroidal shapes for melting snowflakes in the absence of aggregation within the ML yield much lower values of δ than observed especially at S band (Trömel et al., 2013). Contrary to our expectations δ observations at S band showed much higher magnitudes than the δ observations at X band. Maximal observed δ at X band is 8.5°, whereas maximal observed δ at S band is 40°. Since all X band observations are from Germany and all S band observations taken into account are from the US, part of this effect may be attributed to the climate difference between the U.S. and Germany.

In the future, measurements of δ can probably be utilized as an important calibration parameter for improving microphysical models of the ML. Larger δ should be associated with larger size aggregates above the ML. However, no correlation between δ and the depth of the cloud have been identified so far. Some link may exist between the appearance of the zone of dendritic growth aloft and δ within the ML. The signature for dendritic growth has already been identified in several of the German event and needs further investigations. In summary, the δ signature definitely contains very important microphysical information, which has to be further explored.

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