11B.3 ON THE VARIATION OF THE PARAMETRIZATION OF RAINFALL RATE ESTIMATION BY DUAL POLARIZATION TECHNIQUES

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1. INTRODUCTION

Since the early days of radar meteorology estimation of rainfall rate by weather radar is of strong interest. It is practice to apply *Z-R* relations to convert radar reflectivity (*Z*) to rainfall rates (*R*). However, it was found that different *Z-R* relations are necessary to cover the wide variety of natural rain events.

Linear polarized radar techniques enabled to adapt more precisely to the drop-size distribution. Seliga and Bringi (1976) introduced the differential reflectivity (Z_{DR}) as an additional parameter. Since then various methods have been proposed to get more accurate estimates of the rainfall rate. Z-Z_{DR}-R relationsfor C-band radars were proposed by Scarchilli et al. (1993). More recently the specific differential propagation phase (K_{DP}) was shown to give more accurate measurements of the rainfall rate. This was first done for S-band and later for C-band radars. Combination of K_{DP} and Z_{DR} were used to improve the rain rate estimation as well as to compensate for phase changes due to backscatter phase. The combination of K_{DP} and Z_{DR} is frequently used for self-consistency of the calibration and retrieval process.

2. DIFFERENTIAL REFLECTIVITY AND PHASE SHIFT

Seliga and Bringi (1976) proposed a procedure to estimate precipitation parameters more accurately with a polarimetric radar. They used the differential reflectivity (Z_{DR}) as an additional parameter to supply further information on the drop-size distribution.

Empirical Z-Z_{DR}-R relations for C-band were proposed by Scarchilli et al. (1993). Their regression coefficients are based on the simulations of the scattering properties of a wide range of natural drop-size distributions (Ulbrich, 1983). This relation was sensible to low Z_{DR} values and was therefore modified by Gorgucci et al. (1994). Their formulation, the "robust estimator" ($R = 0.0076\, Z_H^{0.93}\, 10^{-0.281\, ZDR}$, with R in mm/h, Z_{DR} in dB, and Z in mm^{6}m^{-3}) behaves like a conventional *Z-R* relation for low Z_{DR} values.

One major disadvantage of Z_{DR} measurements at C-band is the differential attenuation by strong rain. Differential attenuation decreases Z_{DR}, leading to an overestimation of the rain rate by any Z-Z_{DR}-R relation.

The differential propagation phase (Φ_{DP}) can be measured with a polarimetric Doppler radar and its slope along the radar beam gives the specific differential phase shift K_{DP}. Relations show that K_{DP} is nearly proportional to the rainfall rate. Phase measurements are absolute measurements. They do not depend on receiver calibration, nor on attenuation by rain or radome, nor on radar beam blockage. Measurements of the differential phase require high accuracy at low rain rates. If this can not be reached, the slope has to be determined over several kilometres.

3. UNCERTAINTIES CAUSED BY DROP SHAPE

Both, Z_{DR} and K_{DP} are functions of drop shape. In common usage are drop shapes as suggested by Pruppacher and Beard (1970). A large number of theoretical and experimental studies have been reported. The equilibrium shape of rain drops can be determined from theory; however, rain drops are observed to oscillate and so deviate significantly from the equilibrium shape. For radar measurements the mean state of rain drops within the pulse volume is of interest. The scatter cross-section of large oscillating drops can be affected considerable by Mie resonances. This effect is obvious for C-band frequencies. Goddard et al. (1994) presented a axis ratio approximation based on S-band radar observations. Keenan et al. (1997) derived a new relation based on a review of literature. New laboratory measurements were performed by Andsager et al. (1999). They put special emphasis on drop oscillations.

Figure 1 shows how rain rates are affected if different axis-ratio parametrizations are assumed. For given drop-size distributions (exponential drop-size distribution, Marshall-Palmer relation) Z_H and Z_{DR} were computed assuming different axis-ratios parametrizatios. A Z-Z_{DR}-R relation was used to estimate the rain rate. The differences in rain rate between the different parametrizations is in the order of 30% for medium rain rates.

4. VARIATION OF THE DROP-SIZE DISTRIBUTION

In order to relate the rainfall rate with radar parameters several procedures are commonly used: i) ground based measurements of *R* together with radar

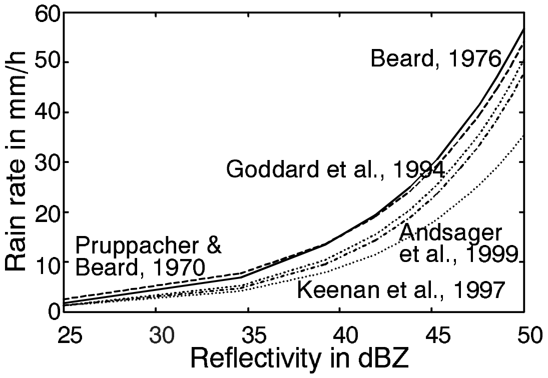

Figure 1. Effect of different axis-ratio parametrizations on the retrieval of the rain rate with a Z-Z_{DR}-R relation.

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measured reflectivity aloft; ii) measured drop-size distributions to estimate R and radar parameters; iii) simulations of drop-size distributions to estimate radar parameters.

Method i) is close to the objective to estimate the rainfall at ground by radar. Methods ii) and iii) do not depend on radar calibration or system performance. However, assumptions are made on the scattering properties of the rain drops. Method iii) additionally requires assumptions on the drop-size distribution.

Three different data sets were used. For method ii) two different disdrometer data set were used. The first one consists of about 12000 1-minute drop-size distributions measured during April to Nov. 1996 at Oberpfaffenhofen. The second one (using the same disdrometer) consists of about 10000 1-minute drop-size distributions measured at Locarno (Sept. - Nov. 1999). The third data set (method iii) consists of simulated drop-size distributions using the range of N_0, D_0 and μ of a Gamma shaped DSD as proposed by Ulbrich (1983). Figure 2 shows how the frequency of rain rate levels for the different DSD's.

5. CONCLUSIONS

Table 1 shows a wide variation of the coefficients for a polarimetric rain rate estimation. The coefficients depend both on drop shape and DSD. Both relations using K_{DP} depend more on drop shape as the Z-Z_{DR} relation. The K_{DP}-Z_{DR} relation is less sensitive on the DSD used. From the available data no clear trend is visible and no conclusion can be drawn which relation or which parametrization of drop shape is more apropriate.

The dependency on drop shape confirms Figure 1. The dependency on the DSD's is mainly caused by the fact that the data sets have a different weight on the distribution of rain rates as shown in Figure 2. Only the simulated DSD's have a considerable contribution of rain rates above 10 mm/h. The other two sets of DSD's are mainly dominated by low rain rates where most drops are spherical and do not contribute much to Z_{DR} or K_{DP}.

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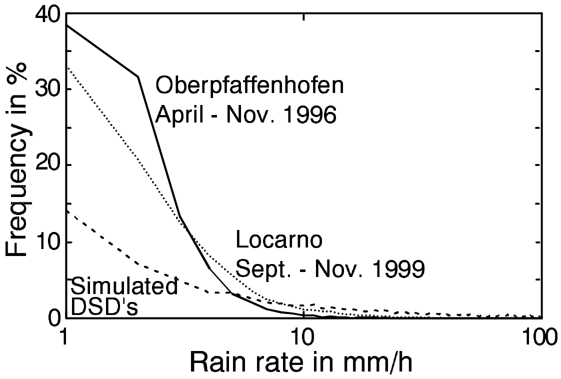

Figure 2. Frequency of rain rate for the three different data sets used for the parameterization.

Table 1. Coefficients of Z-Z_{DR}-R, K_{DP}-R, and K_{DP}-Z_{DR}-R relations for different aris-ratio parametrizations and for different drop size distributions. Units are mm/h for R, mm^6m^{-3} for Z_H, and ° /km for K_{DP}.

Rainfall rate parametrization for different drop-size distributions	Axis-ratio parametrization by		
	Pruppacher and Beard (1970)	Keenan et al. (1997)	Andsager et al. (1999)
Oberpfaffenhofen April - Nov. 1996			
$R = a\, Z_H{}^b\, 10^{cZDR}$	a = 0.0221 b = 0.82 c = -0.45	a = 0.239 b = 0.75 c = -0.40	a = 0.0221 b = 0.76 c = -0.33
$R = a\, K_{DP}{}^b$	a = 18.40 b = 0.79	a = 29.08 b = 0.79	a = 24.87 b = 0.74
$R = a\, K_{DP}{}^b\, 10^{cZDR}$	a = 42.73 b = 0.94 c = -0.22	a = 63.90 b = 0.94 c = -0.25	a = 57.38 b = 0.90 c = -0.22
Locarno Sept. - Nov. 1999 (MAP SOP)			
$R = a\, Z_H{}^b\, 10^{cZDR}$	a = 0.0245 b = 0.81 c = -0.40	a = 0.250 b = 0.76 c = -0.36	a = 0.0215 b = 0.77 c = -0.30
$R = a\, K_{DP}{}^b$	a = 19.66 b = 0.78	a = 28.81 b = 0.77	a = 24.92 b = 0.71
$R = a\, K_{DP}{}^b\, 10^{cZDR}$	a = 41.27 b = 0.92 c = -0.20	a = 58.54 b = 0.91 c = -0.23	a = 52.16 b = 0.86 c = -0.20
Simulated drop-size distributions			
$R = a\, Z_H{}^b\, 10^{cZDR}$	a = 0.0185 b = 0.84 c = -0.31	a = 0.179 b = 0.82 c = -0.30	a = 0.0172 b = 0.82 c = -0.26
$R = a\, K_{DP}{}^b$	a = 25.81 b = 0.84	a = 39.06 b = 0.82	a = 37.14 b = 0.78
$R = a\, K_{DP}{}^b\, 10^{cZDR}$	a = 38.27 b = 0.92 c = -0.13	a = 61.05 b = 0.92 c = -0.19	a = 58.28 b = 0.88 c = -0.17

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