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A new polarimetric scheme for attenuation correction at C band

Alexander Ryzhkov[1], David Hudak[2], and John Scott[2]

[1]University of Oklahoma / National Severe Storms Laboratory, Norman (USA)

[2]Environment Canada, King City (Canada)

1 Introduction

A long-standing problem of attenuation correction at shorter weather radar wavelengths can be efficiently resolved by using measurements of differential phase Φ_{DP} if the radar is polarimetrically upgraded. Original polarimetric method for attenuation correction by Bringi et al. (1990) stipulates that the ratio α_h between specific attenuation A_h and specific differential phase K_{DP} does not vary much for a particular radar wavelength. This assumption, however, is not valid at C band in the presence of large drops associated with anomalously high differential reflectivity Z_{DR}. Several modifications of a dual-polarization rain profiling algorithm have been suggested to address this issue (Carey et al. 2000; Bringi et al. 2001; Lim and Chandrasekar 2006).

In this paper, we describe another possible scheme for attenuation correction at C band. This new methodology was tested on several summer storms in Ontario, Canada, using the data collected by the C-band polarimetric radar recently developed by Environment Canada (Hudak et al. 2006).

2 Scattering considerations

High variability of the coefficient α_h at C band is attributed to strong resonance scattering effects which impact A_h and K_{DP} for raindrop sizes exceeding 5 mm. The dependencies of normalized A_h and K_{DP} on equivolume raindrop diameter are illustrated in Fig. 1. As a result of resonance scattering, the ratio A_h/K_{DP} rapidly increases for drop diameters larger than 5 mm and then tends to decrease at the higher end of raindrop spectrum.

Correspondence to: Alexander Ryzhkov

Alexander.Ryzhkov@noaa.gov

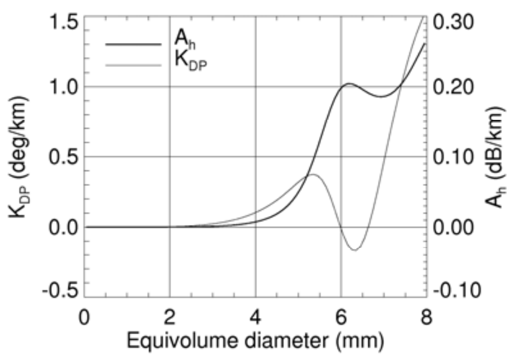

Fig. 1. The dependencies of A_h and K_{DP} on raindrop equivolume diameter at C band (T = 20°C). Raindrop shapes are assumed as in Brandes et al. (2002).

In order to assess variability of the ratio α_h, we simulate A_h and K_{DP} using 25920 drop size distributions (DSD) measured in Oklahoma. The aspect ratio of raindrops was modeled as specified by Brandes et al. (2002). Because vertical dimension of larger drops is smaller than horizontal, one can expect that the resonance effects at vertical polarization are less pronounced than at horizontal and the ratio α_v between specific attenuation A_v at vertical polarization and K_{DP} is smaller and less variable than α_h.

The scatterplots of $A_{h,v}$ versus K_{DP} for all DSDs and for DSDs with Z_{DR} less than 3 dB are shown in Fig. 2. The majority of points for DSDs without large drops ($Z_{DR} < 3$ dB) concentrate along straight lines which means that the $A_{h,v}/K_{DP}$ ratios are quite stable for such DSDs. The points outside of these "line clusters" are attributed to resonance effects due to large drops. It is evident that the A_v – K_{DP} scatterplots are less prone to the resonance effects than the A_h – K_{DP} scatterplots, especially for $Z_{DR} < 3$ dB. Also, attenuation at horizontal polarization is noticeably larger than at vertical polarization for a given K_{DP}, i.e., differential attenuation $A_{DP} = A_h - A_v$ is positive.

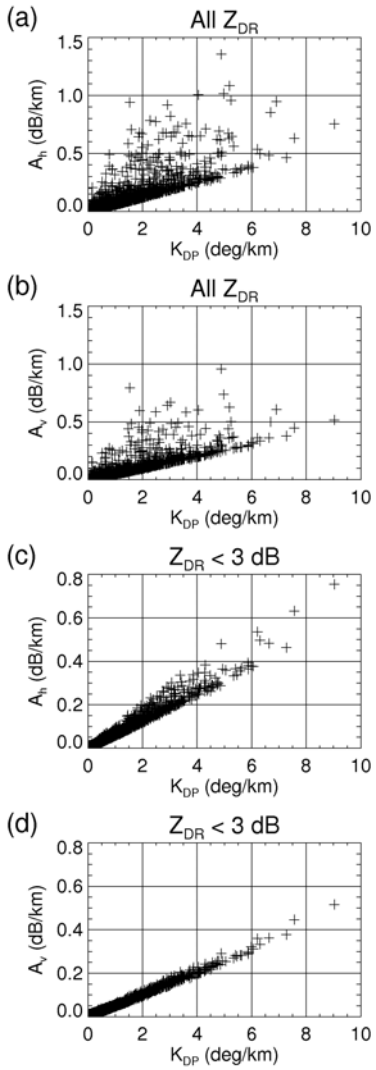

Fig. 2. The scatterplots $A_{h,v} – K_{DP}$ retrieved from 25920 DSDs measured in central Oklahoma. All DSDs are included in panels (a) and (b). Only DSDs with Z_{DR} < 3 dB are included in panels.

Analysis of the scatterplots in Fig. 2 indicates that the major challenge in attenuation correction at C band is occasional "hot spots" along the ray where Z_{DR} > 3 dB and the coefficients $\alpha_{h,v}$ are highly variable. Usually such variations of $\alpha_{h,v}$ occur in relatively small number of range gates but the overall effect of this variability is strong because precipitation intensity and attenuation are high there.

In the suggested correction method, we assume that the ratio $\alpha_{h,v}$ is variable and unknown inside "hot spots", whereas outside of them it is constant and equal to its average climatological value α_0 which depends only on temperature for a given shape – size dependence for raindrops.

Identification of "hot spots" is a crucial component of the algorithm. They can be detected using the 3 dB threshold of Z_{DR} provided that differential reflectivity is corrected for differential attenuation. Alternatively, the 45 dBZ threshold of Z_h can be used after radar reflectivity factor is roughly corrected for attenuation using a simple formula

$$\Delta Z = \alpha_0 \Phi_{DP} \quad . \tag{1}$$

Indeed, the $Z – Z_{DR}$ scatterplot at C band simulated from the measured DSDs reveals that these detection thresholds in Z and Z_{DR} are quite consistent (Fig. 3). In this study, we use the radar reflectivity threshold Z_t = 45 dBZ.

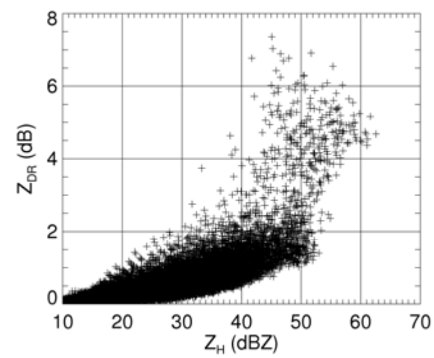

Fig. 3. The scatterplot $Z_H – Z_{DR}$ at C band simulated from the measured DSDs (T = 20°C).

3 Modified ZPHI method

According to the traditional ZPHI method (Testud et al. 2000), the old Hitchfeld – Bordan scheme is used with integral constraint based on the total span of differential phase within the range interval (r_0, r_m) containing radar echo

$$\int_{r_0}^{r_m} A_h(s)\,ds = \int_{r_0}^{r_m} \alpha_h K_{DP}(s)\,ds = \frac{\alpha_h}{2} \Delta\Phi_{DP}(r_0; r_m) \quad , \tag{2}$$

where

$$\Delta\Phi_{DP}(r_0; r_m) = \Phi_{DP}(r_m) - \Phi_{DP}(r_0) \quad . \tag{3}$$

Radial profile of $A_h(r)$ is estimated using attenuated radar reflectivity Z_a and $\Delta\Phi_{DP}$ using the formula

$$A_h(r) = \frac{[Z_a(r)]^b [10^{0.1b\alpha_h \Delta\Phi_{DP}(r_0;r_m)} - 1]}{I(r_0; r_m) + [10^{0.1b\alpha_h \Delta\Phi_{DP}(r_0;r_m)} - 1] I(r; r_m)} \quad , \tag{4}$$

where

$$I(r_0; r_m) = 0.46\, b \int_{r_0}^{r_m} [Z_a(s)]^b ds \tag{5}$$

and

$$I(r;r_m) = 0.46\, b \int_r^{r_m} [Z_a(s)]^b ds \quad . \tag{6}$$

The parameter b is an exponent in the relation $A_h = a\, Z^b$.

In the modified ZPHI method, we assume that

$$\alpha_h(r) = \alpha_0 + \Delta\alpha(r) \quad . \tag{7}$$

In (7), α_0 is a constant climatological value and $\Delta\alpha$ is arbitrary in the gates where intrinsic reflectivity Z exceeds threshold Z_t = 45 dBZ. While $\Delta\alpha$ is allowed to vary from ray to ray, it is supposed to be constant for all gates where $Z > Z_t$ for any particular ray. Correspondingly, the constraint equation (2) can be rewritten as

$$\int_{r_0}^{r_m} A_h(s)\, ds = \alpha_0 \int_{r_0}^{r_m} K_{DP}(s)\, ds + \Delta\alpha \int_{Z > Z_t} K_{DP}(s)\, ds = \frac{\alpha_0}{2} \Delta\Phi_{DP}(r_0; r_m) + \frac{\Delta\alpha}{2} \Delta\Phi_{DP}(Z > Z_t) \quad , \tag{8}$$

where integration in the second integral is performed over range gates where $Z > Z_t$, and $\Delta\Phi_{DP}(Z>Z_t)$ stands for the Φ_{DP} increase within the gates with $Z > Z_t$. Eq (8) stipulates that in the basic formula (4) for the traditional ZPHI method the term $\alpha_h \Delta\Phi_{DP}(r_0;r_m)$ should be replaced with the term $\alpha_0 \Delta\Phi_{DP}(r_0;r_m) + \Delta\alpha \Delta\Phi_{DP}(Z>Z_t)$. This means that two measured differential phase parameters, $\Delta\Phi_{DP}(r_0;r_m)$ and $\Delta\Phi_{DP}(Z>Z_t)$, are used for constraining the procedure instead of one. As a result, radial profile of A_h becomes dependent on the value of $\Delta\alpha$. The appropriate factor $\Delta\alpha$ should be defined from the iterative process of incrementing $\Delta\alpha$ until the following condition is satisfied:

$$\int_{Z < Z_t} A_h(s, \Delta\alpha)\, ds = \frac{\alpha_0}{2} \Delta\Phi_{DP}(Z < Z_t) \quad , \tag{9}$$

where integration is performed over the gates with $Z < Z_t$ and

$$\Delta\Phi_{DP}(Z < Z_t) = \Delta\Phi_{DP}(r_0; r_m) - \Delta\Phi_{DP}(Z > Z_t) \tag{10}$$

A similar procedure can be applied for attenuation correction of radar reflectivity measured at vertical polarization. The use of vertically polarized component of radar signal is particularly recommended for azimuths with substantial attenuation where differential attenuation is also significant and the radar sensitivity is higher at vertical polarization.

4 Validation of the modified ZPHI method

The modified method for attenuation correction was applied to the C-band data collected in south central Ontario during summer of 2005 using the C-band polarimetric radar developed by Environment Canada. Five storms have been examined. They occurred on June 9, June 14, July 14, August 2, and August 19. All five storms produced either hail or significant precipitation causing substantial attenuation of the C-band radiation. Maximal differential phase measured for each of the five storms varied between 100 and 300°. The corresponding maximal attenuation within the radius of observations of 250 km changed from about 10 to 20 dB at horizontal polarization.

We corrected radar reflectivity factor at horizontal polarization only because the corresponding reflectivity at vertical polarization was not directly available from the radar data processor. Based on the results of simulations of A_h and K_{DP} at C band for Z_H < 45 dBZ, T = 20°C, and raindrop shape determined by Brandes et al (2002) we set the parameter α_0 in Eq (7) – (9) to 0.06 dB/deg. We also use b = 0.8 in Eq (4) – (6) as justified by Bringi and Chandrasekar (2001).

The consistency between rain rate fields obtained from K_{DP} and corrected Z_H was used to validate the performance of the suggested method for attenuation correction. Rain rates were computed using formulas

$$R(K_{DP}) = 25.1 |K_{DP}|^{0.777} \mathrm{sign}(K_{DP}) \tag{11}$$

and

$$R(Z_H) = 1.69 10^{-2} 10^{0.0717\, Z_H} \tag{12}$$

derived from 25920 DSDs for C band. In Eq (11) – (12), K_{DP} is expressed in deg/km and Z_H is in dBZ.

As an example, Fig. 4 illustrates the fields of $R(K_{DP})$ and $R(Z_H)$ for the storm on August 19, 2005 which triggered flash flooding in Toronto. It is obvious that rain rates estimated from uncorrected Z_H are heavily underestimated compared to $R(K_{DP})$ (Fig.4b). Rain rates remain negatively biased if the traditional ZPHI algorithm with fixed α_0 = 0.06 dB/deg is utilized (Fig. 4c). The best match between $R(K_{DP})$ and $R(Z_H)$ is achieved if the modified ZPHI method is applied (Fig. 4d). Average value of $\Delta\alpha$ in the area of heavy precipitation with Z_H > 45 dBZ is close to 0.04 dB/deg. Hence, in the cores of rain cells in Fig. 4 the ratio A_h/K_{DP} is about 0.10 dB/deg.

Our analysis of five rain events shows that the difference between attenuation-related biases in the radar reflectivity factor estimated from the standard and modified ZPHI methods can be as large as 4 dB which may project into about two times difference in the corresponding rain rates.

5 Conclusions

Strong resonance scattering effects at C band cause high variability in the ratio $A_{h,v}/K_{DP}$ for raindrops larger than 5 mm.

Such an uncertainty negatively impacts the quality of attenuation correction if the standard ZPHI rain profiling algorithm is utilized.

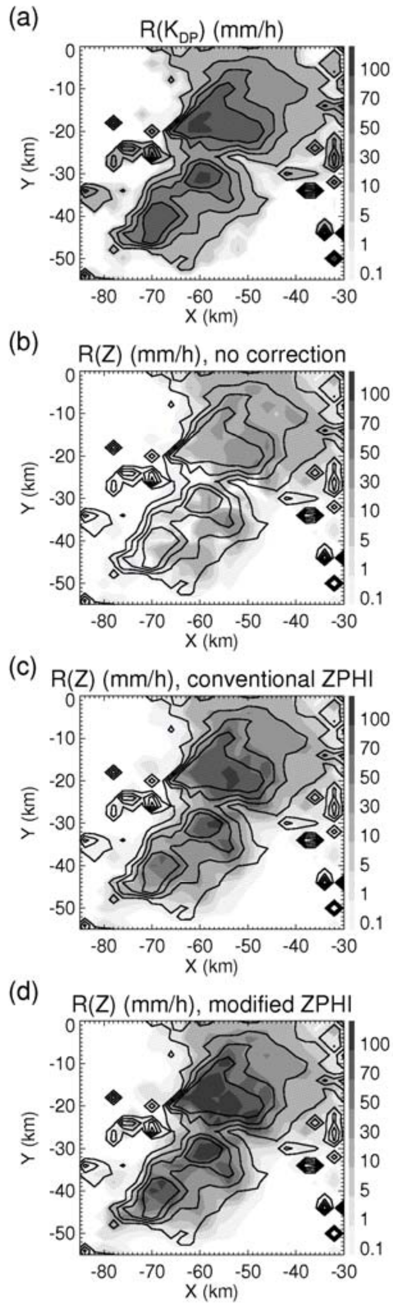

Fig. 4. The fields of rain rates estimated from (a) K_{DP}, (b) uncorrected Z_H, (c) Z_H corrected for attenuation using conventional ZPHI method, and (d) Z_H corrected for attenuation using modified ZPHI method. The data have been collected on 08/19/2005 by the Environment Canada C-band polarimetric radar in south central Ontario.

A modification of the ZPHI method is suggested to mitigate the problem. This implies the use of different constraint in the algorithm.

In the presence of heavy attenuation, it is more advantageous to use radar reflectivity at vertical polarization because vertically polarized radar signal is less attenuated in rain and is less vulnerable to the resonance scattering effects.

A preliminary test of the suggested technique was performed using the C-band polarimetric data collected for five storms in south central Ontario, Canada.

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