ON THE RELATIONSHIP BETWEEN Z-R, THE BRIGHT BAND INTENSITY AND Z_{DR}

4A.3 ***IN STRATIFORM PRECIPITATION***

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1. INTRODUCTION

In Berenguer and Zawadzki (2008), we found significant correlation between the intensity of the bright band, $\Delta_{\text{peak-to-rain}}$, (defined as in Fabry and Zawadzki 1995) and the residuals in the estimates of rainfall, R, obtained from radar reflectivity, Z, using a climatological *Z-R* relationship. This result can be explained by the fact that the dominant processes in snow growth (deposition, riming, aggregation…) determine the characteristics of the bright bands, and, similarly, result in characteristic rain Drop Size Distributions, DSDs (Waldvogel 1974; Huggel et al. 1996; Zawadzki and Lee 2004): large snow aggregates result in much more intense bright bands than dense rimed particles, and also give rise to a greater number of large drops (which results in an overestimation of rain rate using an average *Z-R* relationship).

On the other hand, many authors (see, for instance, Chandrasekar and Bringi 1988; Ryzhkov et al. 2005; Lee 2006) have shown the interest of using differential reflectivity, Z_{DR}, together with Z (usually at horizontal polarization, Z_h) to improve estimates of R. In this sense, Seliga and Bringi (1976) argued that Z_{DR} is a measure of the mean drop size and independent of the number concentration and strongly affected by the presence of large drops.

This suggests that $\Delta_{\text{peak-to-rain}}$ and Z_{DR} may contain some common information. Here, we have studied the possible relationship between these two variables, and compared their skill in improving rainfall estimates.

2. DATA USED

The data used here are correspond to the time series of reflectivity and Doppler velocity profiles observed with a UHF wind profiler, and to the DSDs measured with a POSS disdrometer (Sheppard 1990). These two instruments were collocated on the roof of a 14-storey building in downtown Montreal, Quebec (Canada) in the period April 1994 to October 2000. Here we have analyzed 22 events totalizing 85 hours of stratiform rainfall at ground.

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2.1 *UHF profiler data*

Vertical profiles of reflectivity and Doppler velocity have been measured with a UHF profiler at 915 MHz, with height and time resolutions of 105 m and 30-60 seconds, respectively.

From these profiles, we have defined three levels in the melting layer: the bright band top, where melting starts (upper line of black diamonds in the panels of Fig. 1), the bright band peak (white diamonds) as the peak of the reflectivity profile, and the bright band bottom, where snow is completely melted (lower line of black diamonds).

2.2 *DSD data and the climatological Z-R*

DSD observations were obtained with a POSS disdrometer (a low-power, continuous-wave, X-band, bistatic radar developed by Atmospheric Environment Canada). These data have been used to estimate Z_{DR} at ground using the code of Mishchenko et al. (2000), based on the T–matrix approach to model the scattering properties of rain drops. Drop deformation has been computed assuming the model of Brandes et al. (2002).

Measured DSDs have been averaged over a 5-minute window to filter out instrumental and observational noise (as discuseed by Lee and Zawadzki 2005a), and to ensure that the DSD variability in disdrometric observations is equivalent to the variability in the sampling volume of the UHF profiler.

Figure 2 shows the *Z-R* pairs for the analyzed cases, showing, relative good agreement with the climatological Z-R relationship obtained by Lee and Zawadzki (2005b). Also, POSS reflectivity and UHF reflectivity at 735 m match within an error standard deviation of 1.5 dB.

3. THE BRIGHT BAND INTENSITY, Z_{DR} AND THE Z-R RELATIONSHIP

In this study, we have used the residuals in rain rate estimated with the climatological *Z-R* (compared to rain rate calculated from DSD observations), δ, as a proxy for the instantaneous *Z-R* relationship:

$$\delta = 10\log\left[\frac{\hat{R}(Z)}{R}\right] \tag{1}$$

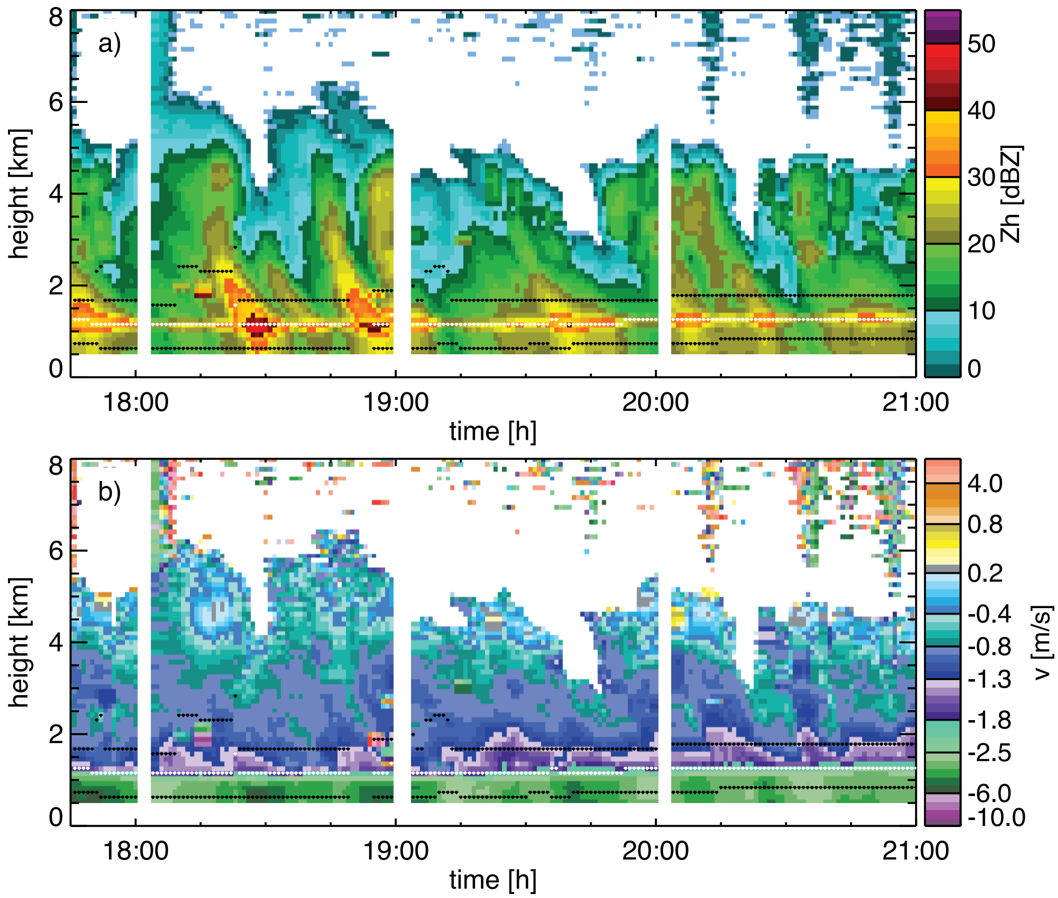

Fig. 1. Time series of vertical profiles of (a) reflectivity, and (b) Doppler velocity as observed by the McGill UHF profiler on 03 December 1998 from 17:45 to 21:00 UTC. The upper (lower) line of black diamonds on both panels indicates the height where particles start to melt (are completely melted), and the line of white diamonds shows the location of the peak of the reflectivity profile.

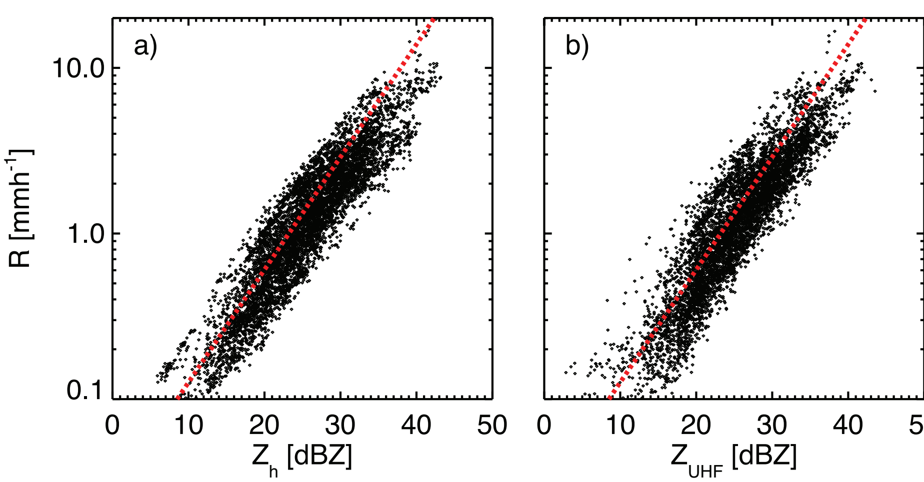

Fig. 2. Scatter plot of Z-R pairs corresponding to the entire data set analyzed in this study: (a) as computed from POSS observations, and (b) for reflectivity observed with the UHF profiler at 735 m. The red dotted lines correspond to the climatological relationship, Z=210$R^{1.47}$.

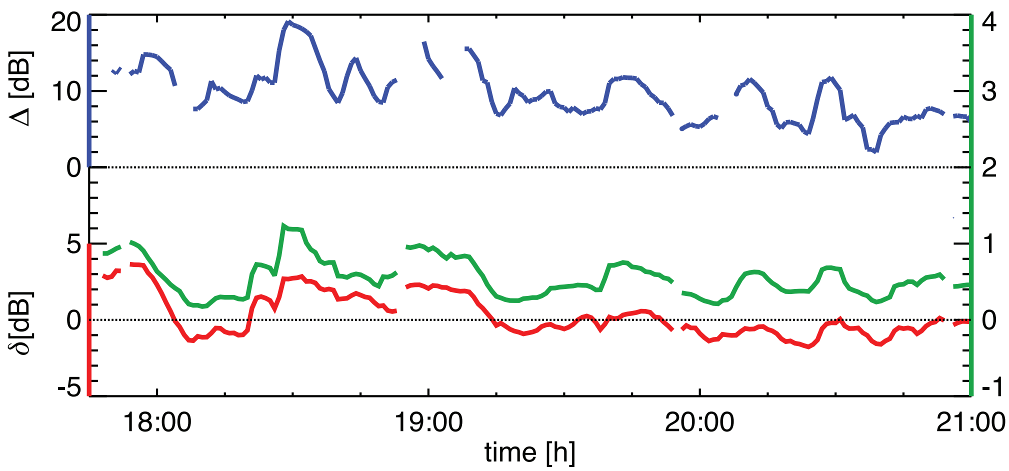

Fig. 3. Time series of $\Delta_{peak\text{-}to\text{-}rain}$ (blue line), Z_{DR} (green line), and δ (red line) for the case of 03 December 1998 from 17:45 to 21:00 UTC. $\Delta_{peak\text{-}to\text{-}rain}$ has been obtained from UHF observations (see Fig. 1a), and Z_{DR} and δ, from DSD measurements.

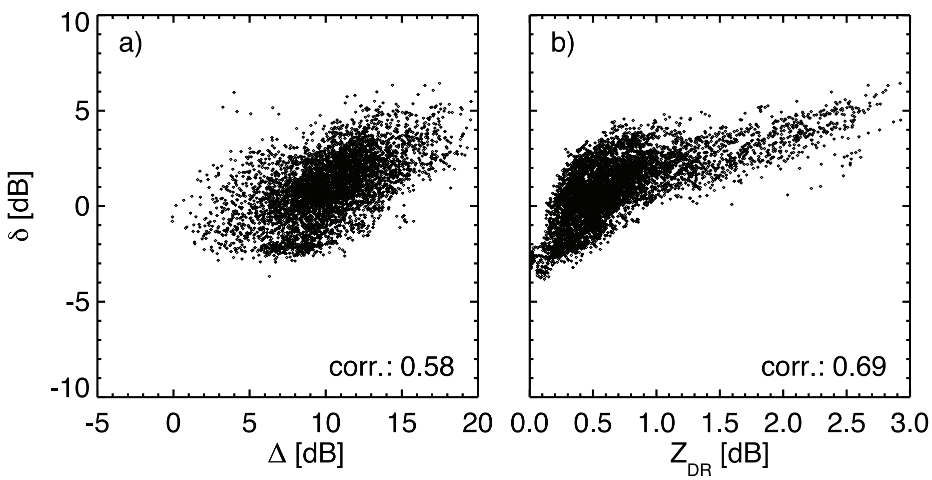

Fig. 4. Scatter plots of (a) $\Delta_{peak\text{-}to\text{-}rain}$ vs δ, and (b) Z_{DR} vs δ for the complete data set analyzed in this study.

Figure 3 shows the time series of $\Delta_{peak\text{-}to\text{-}rain}$, Z_{DR} and δ for the event of 03 December 1998. It is quite apparent how the fluctuations of δ are corresponded by fluctuations in Z_{DR} and $\Delta_{peak\text{-}to\text{-}rain}$. This results in correlation between $\Delta_{peak\text{-}to\text{-}rain}$ and δ of 0.80 (0.85, between Z_{DR} and δ).

The scatter-plots of $\Delta_{peak\text{-}to\text{-}rain}$-$\delta$ and Z_{DR}-δ for all the events analyzed here are presented in Fig. 4. The two scatter plots show significant correlation between the analyzed variables and δ (0.58 for $\Delta_{peak\text{-}to\text{-}rain}$, and 0.69 for Z_{DR} -0.72 in logarithmic units-).

On the other hand, we have also investigated the amount of common information contained in $\Delta_{peak\text{-}to\text{-}rain}$ and Z_{DR}. As it is well known (e.g. Ryzhkov et al. 2005), Z_{DR} is strongly correlated with Z_h (see Fig. 5). We have, thus, analyzed the improvement in explaining Z_{DR} by means of Z_h and $\Delta_{peak\text{-}to\text{-}rain}$ (Fig. 6). This leads to an improvement in the root mean square error (RMSE) of Z_{DR} estimates of about 10% (from 0.27 dB to 0.24 dB, when $\Delta_{peak\text{-}to\text{-}rain}$ is used). On the other hand, the direct correlation of $\Delta_{peak\text{-}to\text{-}rain}$ and Z_{DR} is of 0.45. Although these results do not let us to make any definitive conclusion on the correlation between $\Delta_{peak\text{-}to\text{-}rain}$ and Z_{DR}, in cases such as the one presented in Figs. 1 the correlation between the two (blue and green lines, respectively, in Fig. 3) is 0.80.

4. RAINFALL ESTIMATION USING Z_h, $\Delta_{peak\text{-}to\text{-}rain}$ AND Z_{DR}

Figure 7 presents the scatter-plots of rainfall estimates, obtained by means of (i) the climatological R-Z power-law mentioned above, and (ii) the best fit of $R=aZ_h^b$ to the dataset of observations. The quality of rainfall estimates has been evaluated in terms of the RMSE and the root mean square relative error, RMRE:

$$RMSE = \left[\frac{1}{N} \sum_{i=1}^{N} (R_i - \hat{R}_i)^2 \right]^{\frac{1}{2}} \tag{2}$$

$$RMRE = \left[\frac{1}{N} \sum_{i=1}^{N} \left(\frac{R_i - \hat{R}_i}{R_i} \right)^2 \right]^{\frac{1}{2}} \tag{3}$$

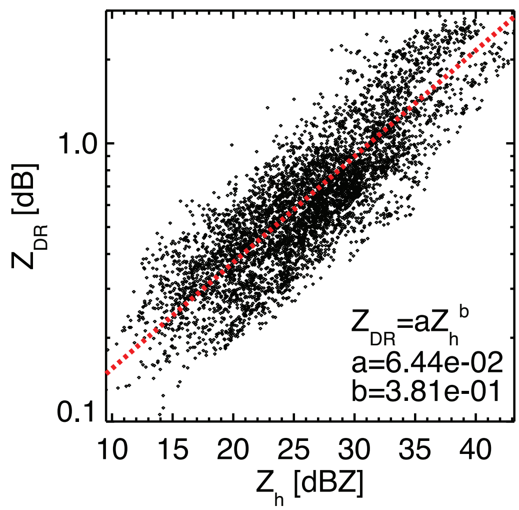

Fig. 5. Scatter plots of Z_h vs Z_{DR} for the complete data set analyzed in this study. The red dotted line corresponds to the best fit.

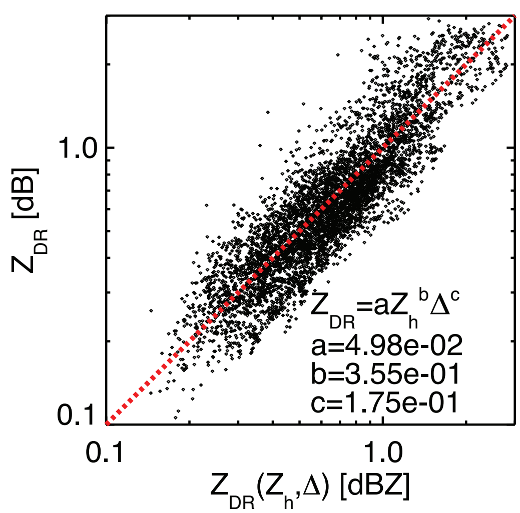

Fig. 6. Scatter plots of Z_{DR} as estimated from $\Delta_{peak\text{-}to\text{-}rain}$ and Z_h vs Z_{DR} for the complete data set analyzed in this study.

By using the fitted R-Z power-law, the RMSE (RMRE) was reduced from 1.68mmh^{-1} (63%) for the climatological *Z-R* to 0.85 mmh^{-1} (33%).

Several authors have used the information of Z_{DR} on the DSD to improve rainfall estimates, $\hat{R}$, by using Z_h and Z_{DR}, compared to the single-parameter R-Z_h forms. In our case, the following form has shown to provide the best rainfall estimates (see the R-$R(Z_h,Z_{DR})$ scatter-plot in Fig. 8a):

$$R(Z_h, Z_{DR}) = aZ_h^b Z_{DR}^c \tag{4}$$

This expression is very similar to that used by Chandrasekar and Bringi (1988); Chandrasekar et al. (1990) or Lee (2006). In fact, the parameters of our fit (a=2.03·10^{-3}, b=0.97 and c=-1.09) are almost identical to those reported by Chandrasekar et al. (1990). By using Z_{DR}, the errors significantly reduced to RMSE=0.41mmh^{-1} and RMRE=14%.

Similarly, the correlation between $\Delta_{peak\text{-}to\text{-}rain}$, and the residuals in R, δ, stimulated us to analyze the possibility of using $\Delta_{peak\text{-}to\text{-}rain}$ to improve the estimates of rainfall according to:

$$R(Z_h, \Delta_{peak-to-rain}) = aZ_h^b \Delta_{peak-to-rain}^c \tag{5}$$

Figure 8b shows the scatter plot of R-$R(Z_h,\Delta_{peak\text{-}to\text{-}rain})$. The comparison of this scatter plot with those of Fig. 7, shows that the RMSE (RMRE) improves from 1.68 mmh^{-1} (63%) for the climatological *Z-R* and 0.85 mmh^{-1} (33%) for the fitted Z-R to 0.70 mmh^{-1} (29%) when $\Delta_{peak\text{-}to\text{-}rain}$ is used. The more improvement in the RMSE compared to the RMRE indicates that the error reduction is more significant for the high rainfall rates.

Additionally, it is worth noting that the exponent *b*=0.62 of equation 5 fitted to our data set is very close to that estimated for the exponent *b*=0.68 of the climatological power-law $R_{clim}(Z)=aZ^b$ (see Fig. 7a). This means that this best fit is almost equivalent to use $\Delta_{peak\text{-}to\text{-}rain}$ to estimate δ (see equation 1).

5. CONCLUSIONS

In this study we have analyzed the correlation between Z_{DR} and $\Delta_{peak\text{-}to\text{-}rain}$ in stratiform precipitation, and how they can explain the residuals in R when using a climatological Z-R.

Although the use of $\Delta_{peak\text{-}to\text{-}rain}$ together with Z_h only reduces the RMSE in Z_{DR} by about 10%, we have found that, in some cases, these two variables present strong correlation. More analysis on this topic would be required to identify the specificities of such cases.

We have shown that both Z_{DR} and $\Delta_{peak\text{-}to\text{-}rain}$ partly explain the residuals in R resulting from the climatological Z-R relationship. This correlation suggested that the estimates of R could be improved by using those parameters together with Z_h.

The use of Z_{DR} for rainfall estimation is quite more effective at reducing the RMSE and the RMRE than $\Delta_{\text{peak-to-rain}}$. However, one has to notice that in this study we have used Z_{DR} obtained from disdrometer measurements, which are also used to estimate R. In this sense, the uncertainty associated to the measurements of Z_{DR} from an independent instrument (e.g. a scanning radar) should make us expect larger errors.

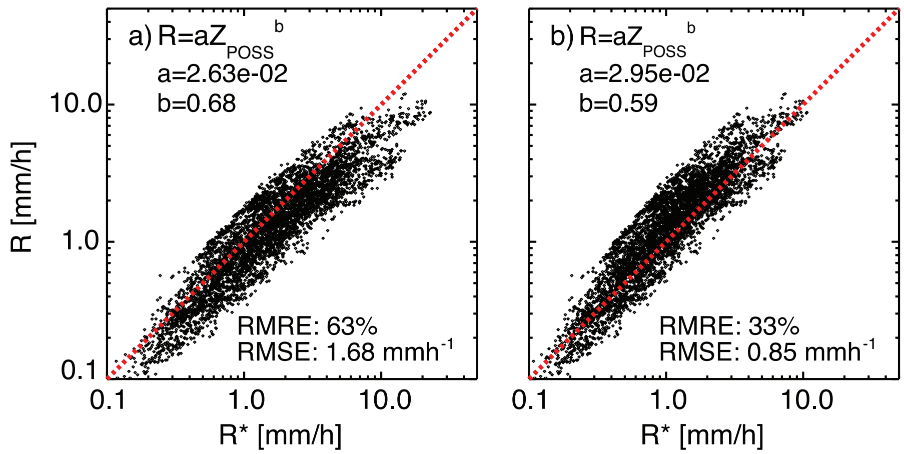

Fig. 7. Scatter plot of R as estimated from Z_h using (a) Z=210$R^{1.47}$, and (b) the power law fitted to the observations (R=0.0295$Z^{0.59}$).

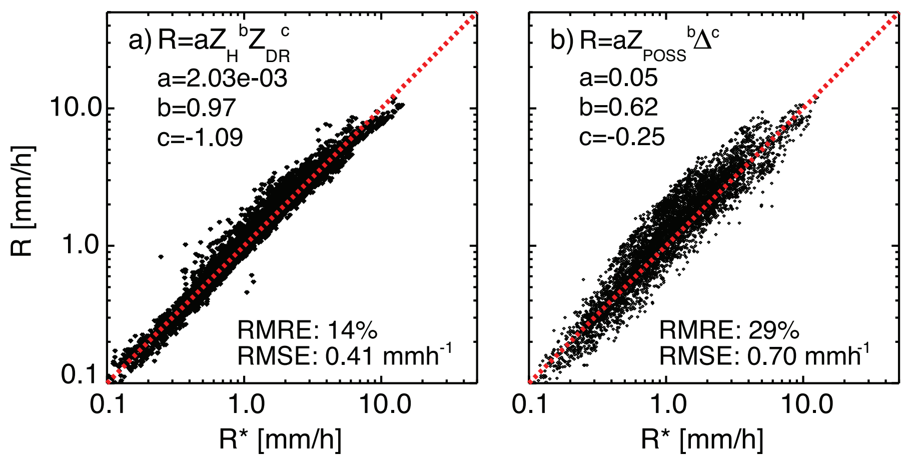

Fig. 8. Scatter plot of R as estimated from (a) Z_h and Z_{DR}, and (b) Z_h and $\Delta_{\text{peak-to-rain}}$.

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