4B.6 ERROR STATISTICS OF VPR CORRECTIONS IN STRATIFORM PRECIPITATION

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1. INTRODUCTION

The need to correct for the enhanced reflectivity caused by the melting layer when estimating surface rainfall with radar data has been given considerable attention in Europe, Smyth and Illingworth (1998), Vignal et al. (2000), Germann and Joss (2002) and references therein. While the emphasis in the U.S. has understandably been mainly with severe convective weather, this problem has also been recognized, Vignal and Krajewski (2001). A preliminary correction of radar-generated rainfall maps on the basis of range-dependent vertical profiles of reflectivity (VPR) has been implemented operationally with the McGill radar, Bellon and Kilambi (1999). However, any correction algorithm does not completely eliminate errors associated with the VPR and range effects. Thus, the purpose of this work is to evaluate the residual errors of various schemes in purely stratiform events.

2. METHODOLOGY

We simulate how the 3-D measurement of reflectivity at close range would be sampled by the radar at various ranges and heights. The simulated measurements are then compared with the known fine resolution data close to the surface at near range. This approach has the advantage of isolating errors due solely to the VPR while ignoring all other sources of errors that would be present when comparing radar measurements with gauges. The RMS error of uncorrected and corrected accumulations over various time intervals and spatial resolutions is then derived as a function of height and range, (2-D error structure). Over 250 hours of radar data with mainly stratiform precipitation distributed among 21 events from 8 years have been used for our study.

The 'fine resolution' or 'true' 3-D field is taken to be a sector 20 km in range between 15 and 35 km as measured by the 24 elevation angles (0.5° to 34°) of our S-band scanning radar at a spatial resolution of 1 km by 1°. The azimuthal size of the sector has been chosen to be between 120 and 320 degrees in order to minimize the area extent of ground echoes present elsewhere near our radar location. This 3-D field, centered at r_0=25 km, is placed at 5 farther ranges in discrete increments of 40 km and centered at *r*=50, 90, 130, 170 and 210 km. It is then re-sampled assuming a Gaussian beam width of θ=0.86 degrees.

Thirty Cartesian CAPPI maps, spaced 0.2 km apart in height, the lowest centered at h_0=1.1 km and the highest at 6.9 km, are then generated at a spatial resolution of 2 km from the simulated 3-D polar data. At every radar cycle (5 minutes), the data at the inner sector are used to derive a VPR. It is desirable to integrate the 'instantaneous' VPRs over a suitable time interval (Δt=30 minutes) in order to avoid unrepresentative correction factors based on transient conditions or on too few data points. Since it is necessary to stratify the results by the height of the bright band (BB), we have applied an automatic BB identification algorithm to these space-time averaged VPRs. The distribution of the height h_{peak} of the 211 hours of identified BBs is shown as part of Fig. 3. These VPRs are then smoothed by a Gaussian beam in order to simulate their appearance at various ranges. However, unlike the 2-D smoothing in the azimuthal and vertical dimensions applied to the data of the inner sector, VPR smoothing is 1-D. Range-height (*r,h*) correction factors, independent of intensity, are obtained from the reflectivity difference between the simulated reflectivity at (*r,h*) and that of the original VPR at the lowest height, that is, $C(r,h)=VPR_s(r,h)-VPR(r_0,h_0)$. We refer to it as the modified "inner" VPR correction.

"Climatological" profiles from the entire data sample of identified BBs, stratified according to the reflectivity Z_0 at h_0, and 'height-normalized' relative to h_{peak} have been derived. Fig. 1 exemplifies the set of profiles derived from the original near range data and the one from the simulated data centered at 170 km. It was originally thought that the stratification of profiles in terms of Z_0 would help in improving corrections factors which were expected to be at least partly dependent on precipitation intensity. A similar stratification had been performed by Fabry and Zawadzki (1995) by manually following the slanting profiles of a vertically pointing X-band radar. However, such a procedure is not possible with an operational radar. "Climatological" correction factors $C_{clim}(dBZ,r,h_r)$ are obtained as a function of the relative height h_r, range and for intensities within 20 ≤ dBZ≤ 36. The reflectivity 1.2 km below the BB peak is used as reference rather than Z_0.

The limited results presented here are mainly based on 1-hr accumulations computed every 30 minutes, with and without the range-height correction. In order to examine the 2-D error structure, accumulations are computed at each of the 30 CAPPI height slices and at the 6 ranges. If the VPR at a given cycle time T_0 satisfies the selected BB height limits, this cycle and the required number of previous cycles are used to derive the rainfall accumulation, regardless of whether the previous cycles had an identified BB. Accumulations are

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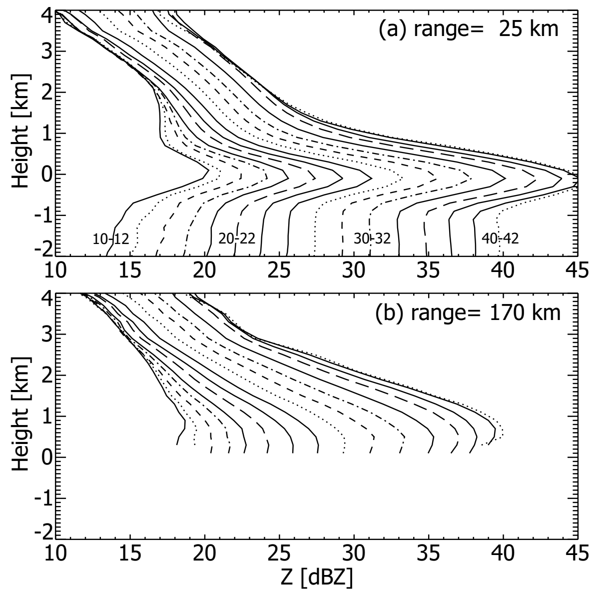

__Fig. 1__: Climatological profiles from 211 hours of stratiform CAPPI maps remapped at a resolution of 2 km, normalized by the height of the BB and stratified according to the surface reflectivity. The set at 25 km is from the original data, the other exemplifies data simulated at a farther range.

generated by simply converting the uncorrected and corrected reflectivity of each CAPPI into a rainfall rate according to the Marshall-Palmer Z-R relationship. They are compared over areas of varying size with the "true" or reference accumulation derived at (r_0,h_0).

3. RESULTS

The RMS error, normalized by the average rainfall R_{ref} over the near-range sector, is used to illustrate the results. NRMS is computed when $R_{ref} \geq 0.01$ mm. The verification over an area of (10x10) km^2 has a more practical significance since it corresponds to a typical small basin and because it eliminates those errors present at the smallest resolution of 2 km that are due to time differences in collecting the 3-D volume scan. Fig. 2 illustrates the results for 2.2 km ≤ h_{peak} ≤ 2.6 km, (82 cases or 41 hours). The uncorrected 1-hr accumulations can easily have errors in excess of 100% if generated from CAPPI maps that are within the influence of the BB, (1.8 to 3.0 km). Only the estimates within ~80 km and below 1.5 km escape contamination, (NRMS < 30%). At any rate, the height of the lowest elevation angle (dash-dotted line) soon traverses the region influenced by the BB forcing errors of the order of 100 to nearly 150% at ranges between 100 and 160 km. The "inner" VPR correction, (Fig. 2b), drastically reduces these errors, extending the 30% contour to a range of nearly 200 km even when estimates are within the BB. Our current real-time BB correction technique that strives to *avoid* rather than to *correct* the reflectivity inside the BB is thus being reformulated. Errors in the snow are somewhat larger, particularly at near range right above the BB peak in the region of a rapid reflectivity gradient. However, for

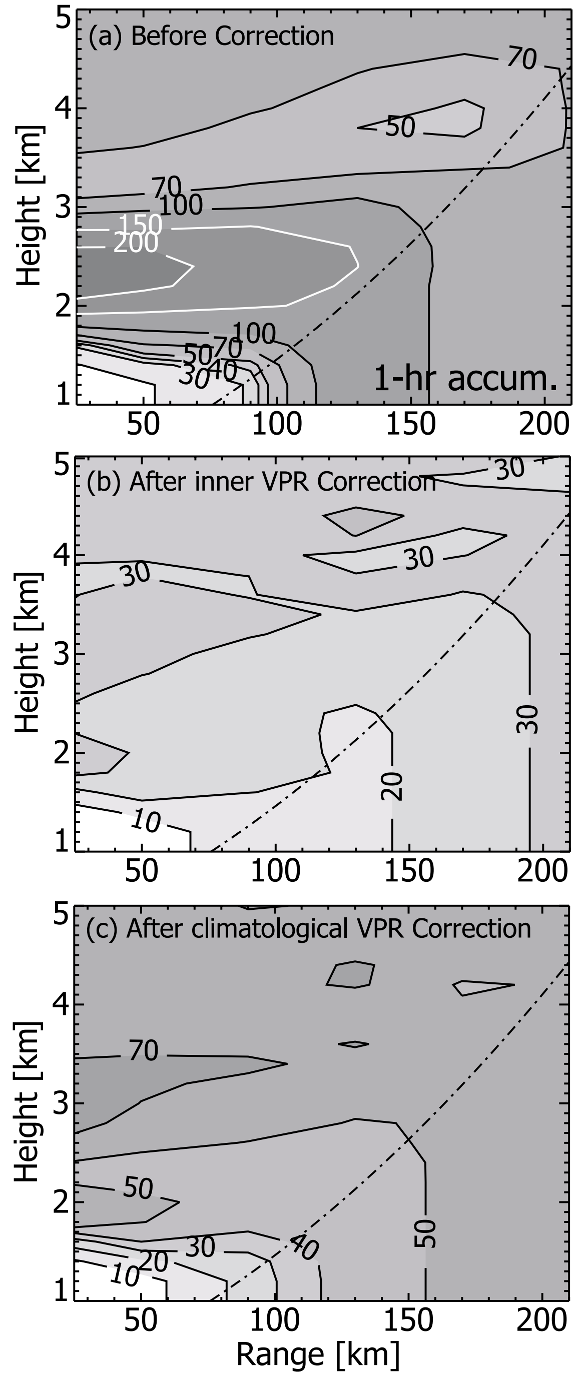

__Fig. 2__: NRMS error at 10-km resolution for uncorrected and corrected 1-hr accumulations for cases of BB heights between 2.2 and 2.6 km, (41 hours of data). The dash-dotted line represents the height of the lowest scanning angle.

practical purposes, rainfall estimates are not made from this region and can thus be ignored. The error reduction so obtained represents a "best-case" scenario because it is implicitly assumed that the "inner" VPR is homogeneous throughout the entire radar range, a condition that is not usually met. The time integration over the previous 30 minutes partially takes into account this problem, yielding a non-zero bias under 10%. The NRMS is only slightly further reduced (~2 to ~5%) by forcing a 0% bias. When the precipitation is only at far ranges, $C_{clim}(dBZ,r,h_r)$ can be used provided the height of the melting layer is known in order to estimate h_r. Mittermaier and Illingworth (2003) state that this height needs to be known with an accuracy of 200 m. Fig. 2c shows that this approach is about half as successful as with the "inner" VPR.

The statistics of importance are those at the "lowest default height" defined as 1.5 km within 100 km and as the height of the lowest elevation angle beyond that range. It is the basis of rainfall accumulation maps in real-time radar operations in Canada. Our results for all the other BB heights for two verification areas are best summarized by Fig. 3 at this variable height. A sudden increase in the NRMS error of the uncorrected accumulations is seen at the range where the lowest elevation angle traverses the BB. This uncorrected error exceeds 100% when relatively low BBs (< 2.6 km) are intercepted by the radar beam at closer ranges. The 1.5 km CAPPI height used for surface rainfall estimates may coincide with a very low BB, resulting in errors of nearly 200%. 'Uncorrected' errors of higher BBs are not as large because they are less intense and less thick than lower BBs and especially, because they are sampled by the lowest scanning angle at far ranges where their influence is smoothed out by a wider beam. The required correction is thus not as drastic as with lower BBs. Note that the combination of statistics from all the BB heights (1.4–4.4 km) masks their true effect.

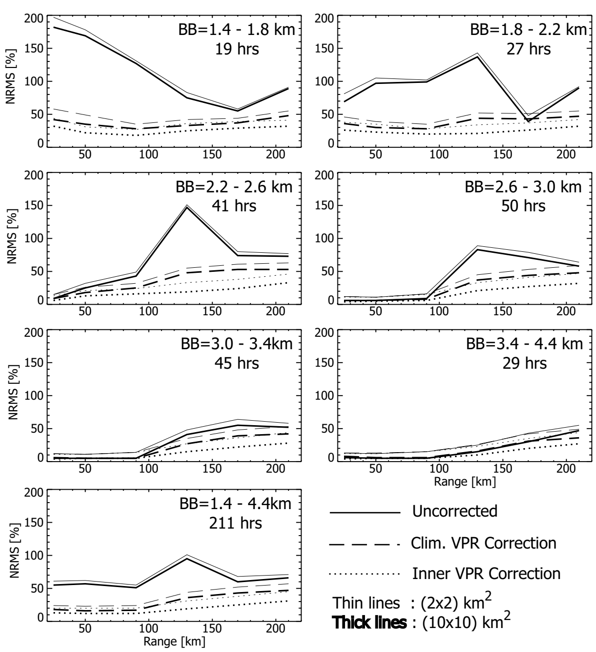

***Fig. 3**: Summary of NRMS errors stratified by h_{peak}. (For 1-hr accumulations at the "lowest default height")*

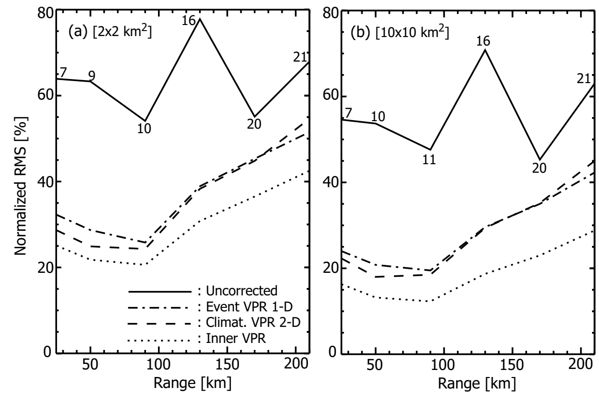

***Fig. 4**: Average NRMS errors for events that satisfy the requirements described in the text. Their number is indicated on the "uncorrected" curve. (For 1-hr accumulations at the "lowest default height")*

Another type of correction has been introduced, one based on the "event" VPR obtained by a time-integration of the VPRs over the entire period of a rainfall event. Range-height dependent correction factors, that remain unchanged during the generation of all the corrected accumulations of a particular event, are derived using the usual Gaussian vertical smoothing technique applied to the 1-D "event" VPR. The results plotted in Fig. 4 are not simply the average of the scores for the 21 events. We want to exclude the scores at ranges when no correction is required since they would greatly diminish the importance of the improvement by the various correction procedures. The score from an event is thus included only if, starting from the near range, the improvement provided by the "inner" VPR is at least 10% better than the uncorrected score. Thus only the scores of events with a low BB that require a correction at a height of 1.5 km are averaged and plotted for the near ranges. It would be improper to combine these cases with events of high BBs when absolutely no correction is required. The number of events that fulfill the above criteria at each range is provided on the uncorrected curve of Fig. 4. The somewhat surprising result is that the correction based on climatological profiles is similar, (actually slightly better at near ranges), that the one based on the "event" VPR. This may be due to the fact that the "climatological" correction is 2-D, (height and intensity), while the "event" VPR is 1-D (height), with no intensity stratification.

Fig. 5 shows that when NRMS is plotted against the logarithm of the verification area a linear relationship is obtained in most cases. For higher BBs, or when errors are not as large, there is a tendency for errors not to be diminished as much with increasing area. In the limit of an area as large as the entire selected sector, the NRMS error reduces to the observed bias.

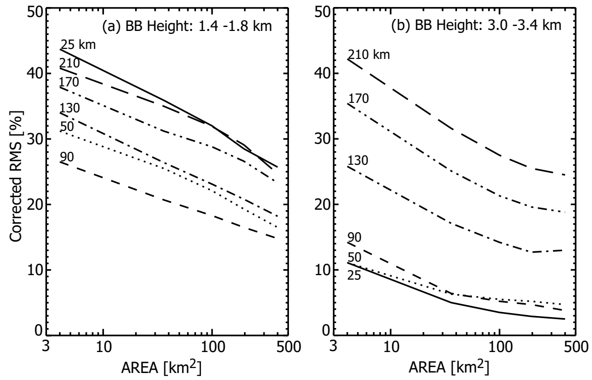

***Fig. 5**: NRMS error after correction by the "inner" VPR method as a function of the verification area. (For 1-hr accumulations at the "lowest default height")*

The dependence of the corrected NRMS on the length of the accumulation interval is given in Fig. 6. The majority of curves exhibit a general exponential behavior, with most of the decrease in NRMS being achieved with an accumulation interval of 45 minutes, (somewhat less, ~20 minutes, when the errors are smaller). We notice an exception at near range with very low BBs, where the initial larger errors (~170%) are not significantly reduced below 35% by increasing the accumulation interval beyond 60 minutes. Increasing the verification area or the length of the accumulation interval reduces the random error but not the bias of a correction scheme.

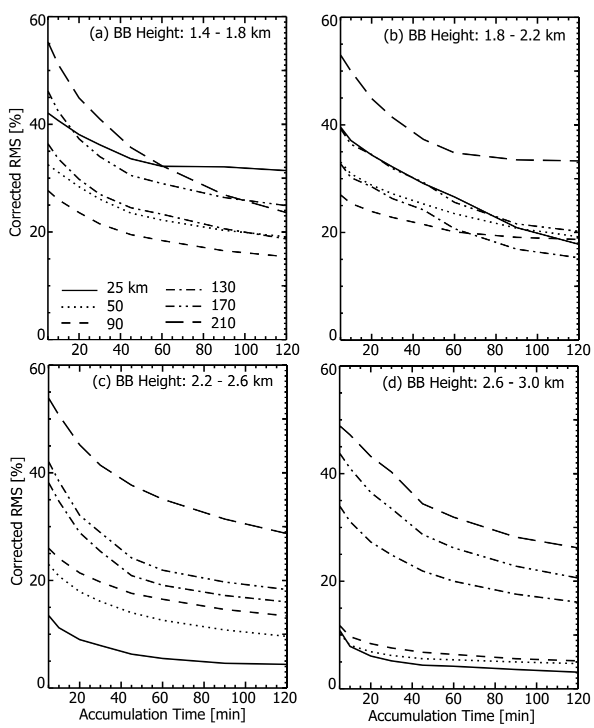

***Fig. 6**: As in Fig. 5 but as a function of accumulation time at 10-km resolution for the indicated BB heights*.

4. CONCLUSIONS

The range-height error structure associated with various VPR correction schemes has been stratified in terms of the height of the bright band for purely stratiform situations. However, statistics giving the dependence on resolution and accumulation interval are best summarized along the "lowest default height". The height of the bright band, the size of the verification area, the length of the accumulation and range are all influential on the final error. For example, errors of less than 20% can only be achieved over larger verification areas (>100 km^2), with longer accumulation intervals (>45 minutes), with bright bands that are relatively high (>2.5 km), and for ranges within ~130 km. In a "worse-case" scenario, these errors derived under the ideal assumption of a constant VPR throughout the radar range must be added to those related to ground clutter removal, the variability of the drop-size distribution, (ie., uncertainty in Z-R relationships), radar calibration, and, in the case of C-band, wet radome and rain path attenuation. VPR correction procedures must differentiate the stratiform and the convective portions of a system for effective real-time operations, particularly at far ranges (>150 km) where convection requiring little or no correction is embedded in light snow requiring a considerable correction. We are using the algorithm of Smyth and Illingworth (1998) and the upper level VIL (Vertically Integrated Liquid water content) for this purpose.

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