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ZR RELATIONSHIPS DERIVED FROM DROP SIZE DISTRIBUTIONS FOR THE CANADIAN RADAR NETWORK

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Introduction

The radar reflectivity factor- rainrate relationship is one of required elements for rain estimation using radar. The first published relationship was by Marshall and Palmer (1948) which continues to be still a cornerstone in the field. Many studies have tried to improve upon it (Batten, 1973). In the tropics, the focus of ZR studies is to partition ZR relationships into convective, stratiform or even transition zone regimes (Steiner et al, 1995; Atlas et al, 1999; Tokay and Short, 1996). Richards and Crozier (1983) did not find operational improvement in partitioning by synoptic situation nor by wind direction. The latter study also found a different ZR relationship from Marshall-Palmer. Considering the body of information currently available, even though the studies were performed relatively nearby, a possible explanation for the difference may be that the relative frequency of weather regimes (convective vs stratiform) are different.

Richards and Crozier (1983) also found that stratifying the data by wind direction or synoptic situation did not reduce the overall variance and that a single relationship in all situations was appropriate. In this paper, we review this study and address the operational issue of what ZR relationship should be used across the meteorologically and geographically diverse Canadian National Radar Network. If there are distinctive convective-stratiform ZR relationships, then there should be different climatological ZR relationships across the country as the relative proportion of weather types vary. Is there is a physical justification for using the same relationship across the country and what should it be?

The Data

Fortuitously, the Automated Weather Observing System (AWOS) Performance Evaluation project provided an opportunity to examine this question. This was a test to certify the operational use of automatic weather stations and involved a verification of the automated with manual measurements. The POSS sensor (Sheppard, 1990) which can measure drop size distributions using a Doppler velocity spectrum approach was part of the evaluation.

In this test, the AWOS sensors were placed strategically across the country in distinct weather regimes to exercise the limits of the instruments. Fig. 1 shows an ecozone map of Canada with the locations of the stations marked. Ecozones are delineate areas based on various characteristics such as climate, and vegetation, which vary from one place to another.

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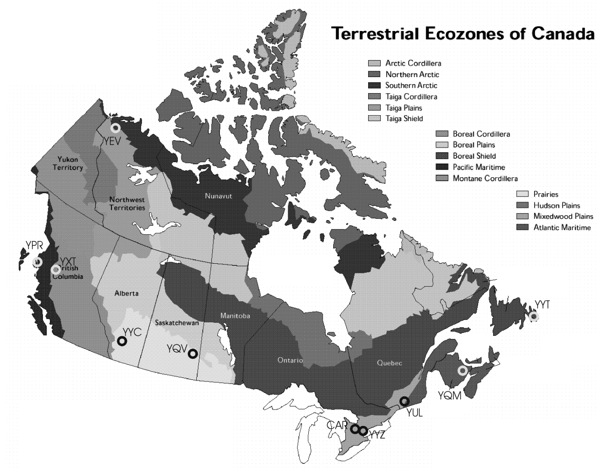

Figure 1: The circles mark the location of the POSS disdrometer. The background map delineates the ecozones used as surrogate for weather regimes. The 3 letter identifiers identify the site.

The POSS produces drop size distribution (DSD) every 60 s from an average of about 380 Doppler spectra (Sheppard and Joe, 1994). One big advantage of the POSS is that the sample volume for large drops is very large and therefore produces stable computations of the radar reflectivity factor which is sensitive to the presence of large drops. The test lasted one year. Ancillary weather data was available.

Z and R were computed from the DSD to produce a self-consistent data set. Only data with wind speeds less than 5 knots were considered. We do not address the issues related to estimating R on the ground from a Z measured aloft but focus on the meteorological precipitation formation mechanisms and geographical and climatological influences.

Analysis and Results

Fig. 2 shows a frequency of occurrence plot for Prince Rupert (YPR on Fig. 1) on a logR-dBZ plot. The dark shading indicates high occurrence of the ZR. For this locale, the POSS is able to detect rain rates lower than 0.01 mm/h and reflectivities less -10dBZ showing the high sensitivity of the instrument to both small and large drops. For this locale, the maximum rainrates and reflectivities are about 10 mm/h and 40 dBZ, respectively. There is a predominant band which defines the ZR relationship. There pattern is asymmetric about this band. There is a weaker parallel band below the main band. Manual observations and individual DSD's indicate that this is drizzle or very light rains. We did not see this in complementary Joss-Waldvogel disdrometer data (not shown).

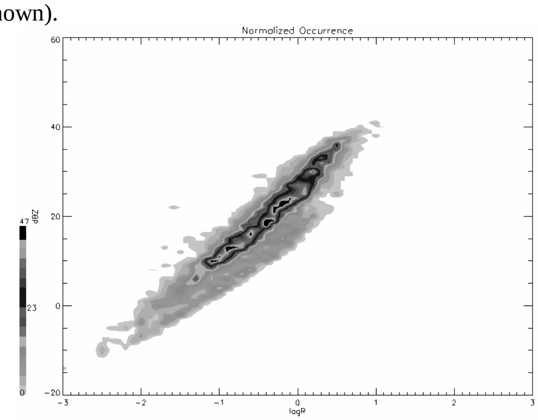

Figure 2: Normalize Occurrence of ZR for the YPR site to illustrate the patterns found. Note the lower boundary of the occurrence pattern.

The data was modelled using a power-law of the form $Z=AR^b$. The choice of curve fitting can affect the results. Most ZR studies regress dBZ on logR, for expediency. This inherently assumes that R is error free (number 2 in Table 1). However, there are other curve fitting options which are described briefly in Table 1. The reference to a root mean square constrained fit in the Table indicates that there is an additional constraint in the total rainrate is preserved.

Table 1: Curve Fit Options

Number	Description
1	logR on dBZ, no error in Z
2	dBZ on logR, no error in R
3	logR on dBZ assuming errors in both
4	dBZ on logR assuming errors in both (should be the same as fit 3).
5	Minimize rms R, constrained
6	Minimize rms logR, constrained
7	Minimize rms R, unconstrained
8	Minimize rms logR, unconstrained

Fig. 3 shows the b coefficient for fit technique 2 and 6 for all the locations in this study. Fit 2 is the simple straight line regression fit on a log-log plot of the dBZ vs logR. Fit 6 is a minimization technique where the coefficients C and d are varied and the minimum in the RMS error, $E = \sum(\log (CZ^d)- \log R)^2$ is found subject to $\sum(CZ^d- R)=0$. The A and b coefficients are derived from C and d. This paper only presents the results from Fit 6, it requires less data to get a stable results since it minimizes relative instead of absolute errors.

Fit 2 produces a lower b coefficient that Fit 6 in all cases. The average b coefficient is 1.5 for fit 2 and 1.7 for fit 6 both with a standard deviation of 0.1 for the entire data set.

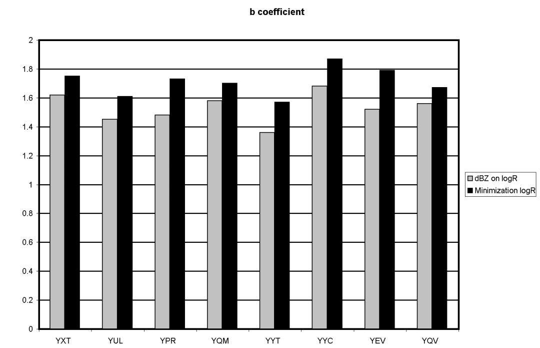

Figure 3: b coefficient for curve fit techniques 2 and 6.

Fig. 4 shows the corresponding A coefficients. The average A value is 340 and 371 for fit 2 and fit 6, with standard deviations of 66 and 79, respectively.

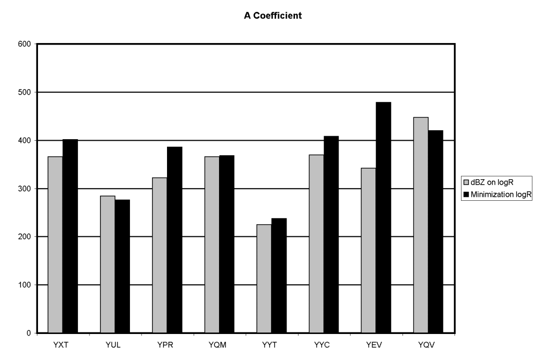

Figure 4: A coefficent for curve fit techniques 2 and 6.

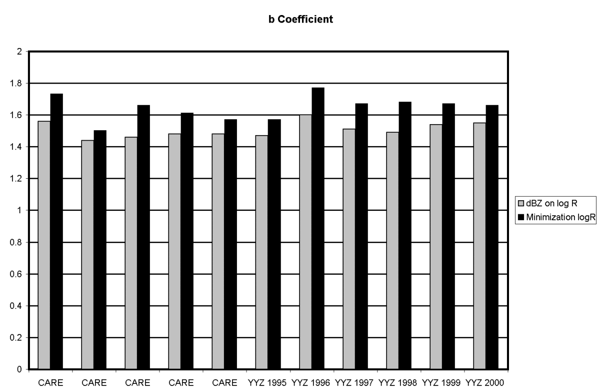

Figure 5: Multi-year average b coefficients for CAR and YYZ sites.

At the CAR and YYZ sites, there were more than five years of data collected. On inspection of Fig. 5, the data indicate a relatively stable coefficient for the two sites which are within 70 km of each other. The average b coefficient for the fit 2 technique is 1.5 with a standard deviation of 0.05. Using the fit 6 technique, the coefficient is 1.6 with a standard deviation of 0.08.

Discussion

To validate and to provide confidence in the POSS DSD's, the DSD derived rainrates were integrated and compared to a tipping bucket raingauge. Results (not shown) indicate excellent comparisons. This is a necessary but not sufficient condition to validate the POSS performance.

Comparison of one season's data with five years of data for the same location show stable results providing confidence that one season's data is sufficient to characterize the climatological ZR relationship. This is counter-intuitive in that the qualitative impression is that there are year to year differences in the weather.

At two of the locations, a Joss-Waldvogel disdrometer was also available for several seasons. Comparisons indicate the JW disdrometer generally produced ZR plots with shallower slopes (not shown). This is attributable to the poor sampling of the large drops by the JW disdrometer. This is verified by producing ZR plots from the POSS data set from which the large drops are truncated.

The POSS is able to measure drizzle drops produced by the warm rain process. The drizzle drop spectra show many small drops and high N_o's and form a distinct ZR regime from the main ZR regime which is presumed to be created by the cold rain process.

Conclusion

Drop size disdrometer data was collected covering the breadth and depth of Canada with the POSS sensor. This study focussed on the general climatological characteristic of the disdrometer ZR relationship.

The manner in which the curve fit is done has a major influence in the results. The traditional least mean squares fit on a dBZ-logR plot underestimates the b coefficient. A curve fit technique minimizing the RMS error in logR with a total rainrate constraint is proposed as a more appropriate technique. This reduces the impact of individual outliers when compared to the minimizing the error in R. There is also an instrumental dependence in that the POSS is able to sample the large drop sizes better than the previous measurement techniques.

The climatological b coefficient is approximately 1.7 with a standard deviation of 0.1 which is very close to the Marshall-Palmer 1.6 and higher than the Richards-Crozier relationship or the Nexrad value of 1.43 and 1.4, respectively. It slightly varies across the Canada. The variation across the country is slightly greater than the year to year variation (0.077).

The climatological A coefficient shows a much greater variation. The average value was 371 with a standard deviation of 79. This is larger than Marshall-Palmer, Richards-Crozier and Nexrad with values of 200, 295 and 300, respectively.

The significant variation in the A coefficient would seem to imply that the ZR relationship should vary from locale to locale. But, since the b coefficients are virtually the same, differences in using a single ZR relationship would show up as a calibration bias. So for climatological applications, a single ZR relationship could be used if this bias is computed.

If a single climatological ZR relationship is used on a daily or event basis, the variation of R for a given Z is substantial. The accuracy (mean standard error about the regression line) would be a factor of two, commonly found in many studies. However, daily analysis, or even better, an event by event (not shown) analysis show much reduced variance in the ZR relationship.

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