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# Radar calibration by gage, disdrometer, and polarimetry: Theoretical limit caused by the variability of drop size distribution and application to fast scanning operational radar data

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**Summary** A long time record of drop size distributions (DSDs) is used to evaluate the effect of the DSD variability on the accuracy of radar adjustment by comparison with a rain gage on a daily basis. Radar and gage measurements are simulated from DSDs. When a single $R$–$Z$ relationship is used in the adjustment of the radar as a hydrological instrument, a standard deviation of fractional error of ~28% is expected. This uncertainty is related to the DSD variability in time. A calibration of reflectivity can be done if a disdrometer is available. This disdrometric radar calibration is not affected by the DSD variability. Thus, the uncertainty that is expected in the radar adjustment with a gage is eliminated. Some uncertainty in radar-disdrometer comparison due to the difference in sampling volumes is minimized by applying a sequential intensity filtering technique (SIFT). Good correlations between radar and disdrometric reflectivities indicate that this could be an excellent way of calibrating radar on a daily basis when a disdrometer is located at close range (less than 30 km) from radar. Furthermore, the consistency of independent checks of radar calibration error with different disdrometers and polarimetry validates the argument that the radar-disdrometer comparison can be used as a tool for absolute radar calibration.

The information from the McGill operational S-band polarimetric radar is also used to calibrate radar. This method is based on the fact that the specific differential phase shift ($K_{DP}$) or differential phase shift ($\Phi_{DP}$) between the horizontal and vertical polarized beams is immune to the radar calibration error whereas the reflectivity is affected by the calibration error. Due to the

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variability of DSDs only, the uncertainty in polarimetric calibration is the standard deviation of 1 dB with a single parameter $K_{DP}$ and reduces to 0.5 dB when the differential reflectivity ($Z_{DR}$) is added as well. To guarantee the stability of this calibration method, data longer than at least an hour is necessary to calculate the calibration error for the fast scanning McGill operational polarimetric radar and contamination by bright band or snow should be avoided. The sensitivity of this calibration method with respect to the drop deformation is tested.


## Introduction

When considering radar calibration there are several areas of interest. On the one hand, the stability of the electronic equipment is a concern in its own right. On the other hand, possible effects of radome on the measurements are a problem that could depend on the state of the radome, whether dry, wet, or with rain streaks. In hydrological applications, calibration of the radar may imply some adjustment to ground truth. That is, the mean bias derived from radar-ground truth comparison can be applied to modify radar measurement. However, the differences between the radar measurements and precipitation intensity at ground may be caused by the height of the radar measurement coupled with the vertical profile of reflectivity, contamination by non-meteorological target, different sampling volume, etc. (Wilson and Brandes, 1979; Zawadzki, 1984; Joss and Lee, 1995; Smyth and Illingworth, 1998; Germann, 2000; Zawadzki et al., 2002; Lee, 2003). When a gage is used as the ground truth, the transformation of radar reflectivity into rain rate is another source of discrepancy (Joss and Waldvogel, 1970; Richard and Crozier, 1983; Doelling et al., 1998; Lee and Zawadzki, 2005a,b). As a result, the mean bias can change event by event even though the radar hardware is stable. Therefore, the mean bias cannot be referred to as a radar calibration error since it is not solely related to the stability of radar. Thus, the use of ground truth such as gage to correct radar measurement is often known as a ''radar adjustment'' and the mean bias is referred to as an ''adjustment bias.'' When these sources of errors are eliminated, the mean bias is related to the absolute stability of radar and can be referred to as a ''radar calibration'' error. Thus, the elimination of these sources of errors is required to use ground truth for the ''radar calibration.''

When a disdrometer is used for the comparison, the transformation with $R$–$Z$ relationships is not necessary because reflectivity can be determined from the drop-size distribution (DSD). However, the sources of errors listed earlier should still be minimized. Differences due to the sampling volume can be reduced by a using long term dataset. Precipitation growth or decay between heights of radar measurement and the ground can be significant for short period due to strong evaporation or interaction of drops. However, in our latitudes there is no significant change of reflectivity (less than 1 dB) below the bright band when a relatively long time is considered (see Fig. 10 in Fabry and Zawadzki, 1995). Therefore, when the radar hardware is relatively stable, the disdrometer data of at least a day can be used for ''radar calibration'' with tolerable uncertainty and the mean bias will be considered as the ''radar calibration error.''

Instead of adjusting radar information to ground truth, radar calibration with radar data themselves is a main priority and provides an independent monitoring of the performance of system. In this sense, additional information from polarimetric radar is a good candidate for the self-consistent radar calibration. Due to inherent characteristics, the specific differential phase shift $K_{DP}$ or differential phase shift $\Phi_{DP}$ between horizontal and vertical polarized beams is immune to the radar calibration (Zrnic and Ryzhkov, 1999). Hence, the combination of $Z_h$ and phase information is one way of monitoring the radar calibration. However, the phase information is noisy (Doviak and Zrnic, 1993) and pixel information can hardly be used in a fast scanning operational radar. In addition, the polarimetric calibration requires sufficiently heavy rain and/or a large spatial extent of precipitation.

In this paper, we analyze the effect of the DSD variability on the precision of radar adjustment/calibration by rain gage, by disdrometer, and by polarimetry. These calibration methods are applied in the McGill operational S-band polarimertic radar. ''Gage'' information is derived from a disdrometer. Thus, hereafter when refer to ''gage'' we mean rain rate derived from disdrometer DSDs. The quality of our radar data are relatively poor because of the fast scanning rate (six rotations per minute) and ground echo contamination. Although our disdrometers are relatively close to the radar (within 30 km), the radar-disdrometer comparison is far from an ideal situation due to ground echo contamination. Radar measurements are taken at a location that is above the ground (0.6–1.2 km) and that is shifted from the disdrometer in range and azimuth to minimize ground clutter contamination. Thus, we are in a situation that has some limitations of an operational radar and far from the ideal research radar set-up. However, we still consider a situation at near ranges so that limitations caused by beam filling and shielding at far ranges should be taken into account when a radar-disdrometer comparison is performed at far ranges. Only rain events are considered and bright band contamination is avoided. The effect of inhomogeneous beam filling is minimized by choosing stratiform events in the radar-disdrometer comparison although this effect can be significant in polarimetric calibration. We also investigate the consistency of calibration results obtained with disdrometer and polarimetry, and evaluate an improvement in rainfall estimation with radar reflectivity when radar adjustment or calibration is applied.

The next section describes the influence of the DSD variability on the precision of radar adjustment by comparing radar derived rain rates with those obtained by a rain gage. In this section radar and gage data are simulated from a dis-