P1.16 CALIBRATION ISSUES USING IMPACT DISDROMETERS FOR CALIBRATION OF DOPPLER RADAR PROFILERS

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1. INTRODUCTION

Doppler radar wind profilers operating at several different frequencies are used routinely as research tools to profile the atmosphere during field campaigns. The ability of these relatively small, moveable profilers to measure the reflectivity and motion of hydrometeors in precipitating clouds has been utilized in many campaigns, including the Hawaiian Rainband Project (HARP) and the Tropical Ocean Global Atmosphere Coupled Ocean Atmosphere Response Experiment (TOGA COARE), and most recently in the Tropical Rainfall Measuring Missions (TRMM) Ground Validation Field Campaigns. For specificity, in this paper we focus our attention on the TRMM-LBA campaign. We compare reflectivity data acquired by a 2835 MHz S-band profiler and a Joss Waldvogel disdrometer combination located at Ji-Parana, Brazil (~ 10 deg S, 62 deg W). The observations were taken during 1999 over 38 days starting on January 23.

To obtain reflectivity factor values in absolute units of dBZ, it is necessary to bring a radar into absolute calibration. It is also desirable to be able to continuously check this calibration. To accomplish these ends we have selected the method of collocating an impact disdrometer (Joss-Waldvogel, or Distromet RD-69) with a vertical looking profiler (Figure 1). The use of the disdrometer as a calibration standard has the added benefit of extending the measurement of the reflectivity factor *Z* to the surface.

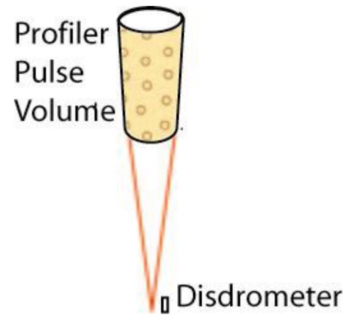

Figure 1: Schematic depiction of the profiler calibration set up. Gage et al. provide a picture of a typical site and typical system parameters in the companion paper 10.6. Williams et al., paper 11.3, discuss using these systems to calibrate scanning radars.

Assuming stability of both instruments and a normal distribution of errors, the calibration offset necessary to bring the observed radar reflectivities into mean agreement with the disdrometer observations can be found to any desired precision just by increasing the number of observations. Thus, the issue with absolute calibration by comparison to a stable standard is one of identifying and reducing systematic errors. There seem to be several systematic issues that currently limit the accuracy of our profiler calibration to ± 1 dBZ or so. If these issues can be resolved, calibration accuracies of the order of ± 0.5 dBZ should be achievable.

It is worth noting that, although we here focus on the calibration problem, many of these issues have broader implications in that they effect precipitation observations in general.

2. THE CALIBRATION TECHNIQUE

The calibration process is quite straightforward. First we select rain events by examination of the disdrometer data. The criterion for a valid

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rain event includes requiring the event have a rain rate sufficient to insure the disdrometer may produce a meaningful DSD. This number may vary from site to site, depending on ambient acoustic noise level, but here we require that the number of drops observed in a minute must be greater than 10. Z_p, the profiler reflectivity factor, is generally taken from the lowest useable profiler range gate, here 202 m AGL.

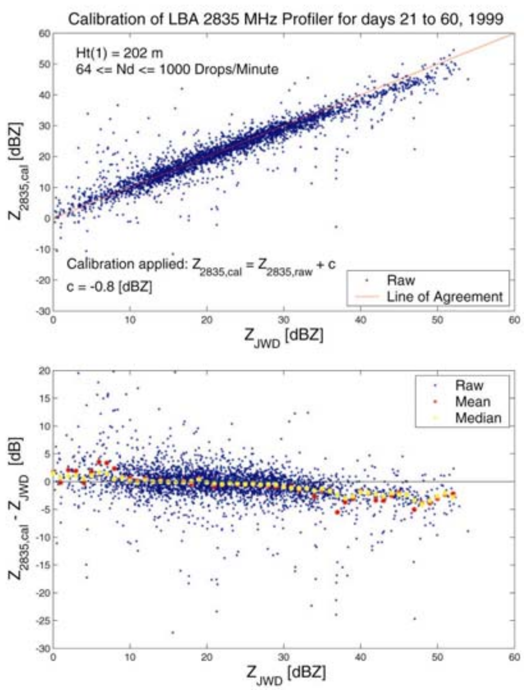


Figure 2: Upper panel: Scatter plot of calibrated profiler Z_{2835} values at the lowest useable range gate (202 m AGL) versus Z_{JWD} calculated from the disdrometer observed surface DSDs. Lower panel: The blue dots show the differences $Z_{2835} - Z_{JWD}$ for each 1 minute long observation. Mean and median differences over 1 dBZ strips of Z_{JWD} are shown. Values of Z_{2835} at low Z are enhanced by clear-air Bragg scatter. The apparent decrease at the high end may be associated with the fact that these large values occur mainly with convective (as opposed to stratiform) situations.

In principle, the next step is simply to adjust the profiler radar constant C_p in such a way that the mean difference of $\delta Z = Z_p - Z_J$, where Z_J is the disdrometer calculated value of Z, goes to zero. This is, in fact, what has been done in Figure 2. However, in practice it is better to consider only a selected band of Z_J to reduce the magnitude of a number of contaminating effects. Some, but not all of these effects are instrument threshold effects, the occurrence of too small a rain-rate for adequate one-minute disdrometer observations, and possible contamination by Bragg scatter of low Z echoes. Though not a problem here, with some highly sensitive systems designed for clear air work it is also necessary to ensure the radar receiver is not saturated.

The exact location of the calibration range may vary from site to site, due to contaminating effects like sea clutter, the strength of local Bragg scatter, or acoustic noise masking of the disdrometer small drop observations. But any band chosen between about 20 to 30 dBZ appears to be adequate (see Figure 2, bottom panel). In theory, and closely enough in practice, the δZ versus Z_J relation is flat, so that selecting a calibration band by thresholding δZ should cause no significant bias.

3. ACCURACY OF OBSERVATION

3.1 The Profiler

One way to get a feeling for the precision of the profiler measurements is to take simultaneous measurements with two of them located side by side. Such a configuration was in place during the 1999 TRMM LBA campaign, when 915 MHz and 2835 MHz profilers were collocated with the im-

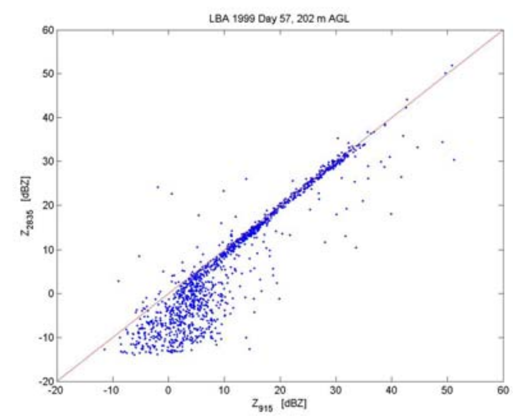


Figure 3: A comparison of Z_{2835} versus Z_{915}.

pact disdrometer. Figure 3 compares the minute-by-minute observations from the radars in a scatter plot of Z_{2835} versus Z_{915}. It is clear that above about 10 dBZ, the observations are linearly and highly correlated, with the exception of a sprinkling of spurious echoes. Below 10 dBZ, the correlation is much poorer, with a tendency for Z_{915} to be larger that Z_{2835}. This is caused by clear air Bragg scatter contributing to the 915 MHz echo power. Since the systems were designed to be equal-sensitive to precipitation, the 915 MHz profiler was necessarily much more sensitive to the Bragg scatter. In addition, viscous damping attenuates Bragg scatter for the 2835 MHz system unless the turbulence is very strong (e. g., VanZandt et al. 2000). For these reasons, the 2835 MHz system is a better choice for precipitation studies in light rain. The overlaid time series in Figure 4 provide another view of these same points. The Bragg scatter enhancement of the 915 MHz return is clearly evident below 10 dBZ.

3.2 The Disdrometer

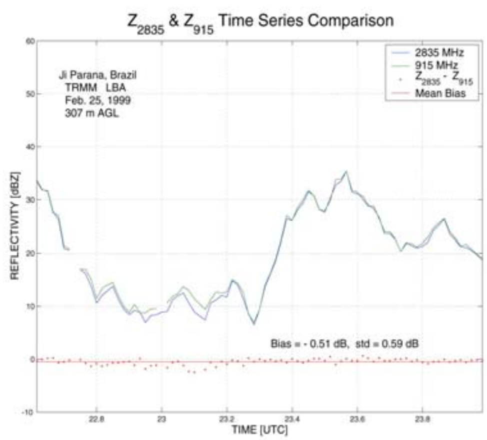


Figure 4: Overlaid time series of Z2835 versus Z915 over an hour and a half of TRMM-LBA, demonstrating the close agreement between the two systems.

We have chosen as our field calibration standard a Distromet RD-69 (a.k.a. Joss-Waldvogel) impact disdrometer. This instrument was chosen because of its rugged construction, stability over time, and extensive use by others

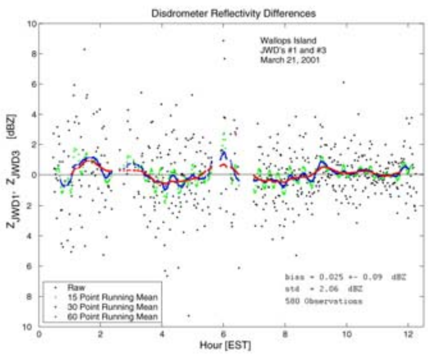


Figure 5: Difference in Z values from two disdrometers 1 m apart.

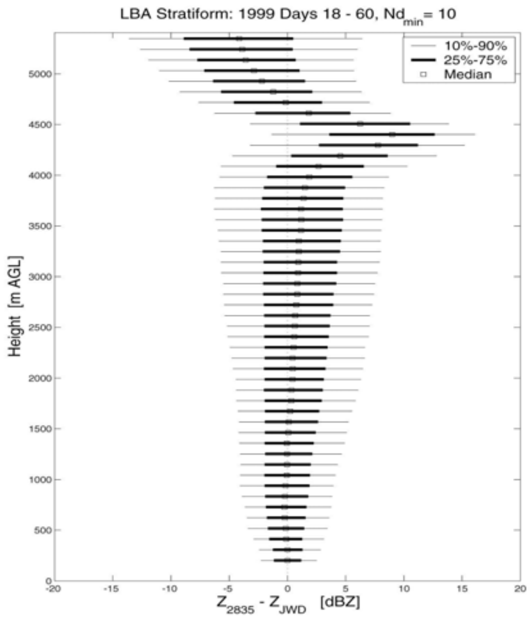
over the last several decades. To get a feeling for the observational time necessary to achieve a given precision, we compared the output of two such disdrometers (neither of which has been used in our radar campaigns) located in a test bed on NASA's Wallops Island facility. The disdrometers were located one meter apart and the analyzed event was a relatively long rainstorm accompanied by strong winds. Observations with less than 10 drops per minute were ignored. Figure 5 shows a time series of the differences between these two disdrometers. Over the entire 570 minutes of observation, the bias converged nicely toward zero, but the 2.1 dBZ standard deviation of the differences is eye opening, leading to a standard error of about 0.1 dBZ over the 570 minutes, or nearly 0.3 dBZ for 60 minutes. Further, it may be clearly seen in this figure that the one minute single observations of Z are very noisy, with excursions as large as plus or minus 6 dBZ. These results are provocative, and suggest further analysis is warranted.

Considering the sample volumes, we may expect that radar observations like those shown in Figure 4 should be less noisy than simultaneous single disdrometer observations. The data shown here say little about this because the conditions and locations of the radar comparison (Figure 4) and the disdrometer comparison (Figure 5) are so different. A campaign locating a profiler in an array of disdrometers is planned for later this year.

3.3 Vertical Structure Bias

The current profiler systems we use can make valid reflectivity observations from two or three hundred m AGL upward through the melting layer and into the ice phase beyond (see Figure

6). The disdrometer, of course, produces surface observations. Thus, there is a two hundred meter



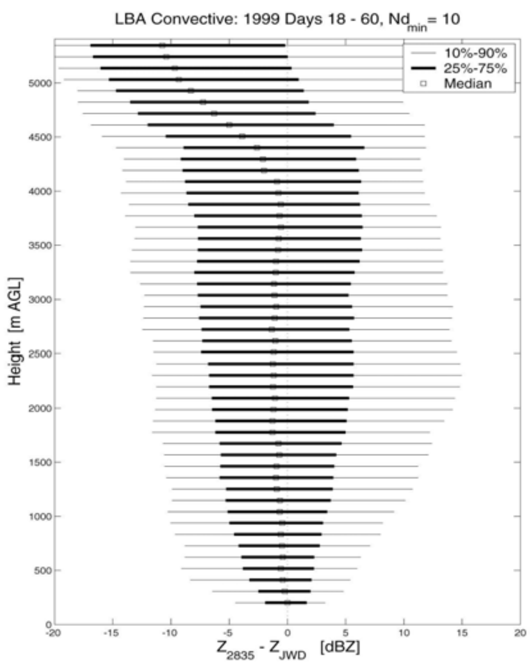


Figure 6: (Upper) Stratiform event δZ versus height for TRMM-LBA days 23-61, 1999. (Lower) Same, but for Convective events. The classification was done by eye: convective had no melting layer.

or so range-gap across which comparison must be made. Tokay et al.,1999 show that at Kapingamarangi in the tropical Pacific the reflectivities for stratiform and mixed stratiform/convective events are, on average, relatively height independent. Thus, these are the events in which changes between the observations at altitude and at the surface are likely to be the least. Figure 6 shows the variation of the median value of Z_p - Z_J versus altitude over the TRMM-LBA site in Brazil. Visual extrapolation to the surface suggests that the 200 m results under stratiform conditions are not significantly biased. At some sites sea clutter causes the comparison to be made from higher up, say 400 to 500 m AGL. The results shown here for an inland, continental site suggest such that even these comparisons should not be in error by more than a dBZ or so for stratiform rain and long averages.

3.4 Residual Slope

When δZ versus Z_J for a large number of observations is plotted (see Figure 2), it is evident that there is a slight linear slope (~0.5 dBZ per decade in Figure 2) between the profiler and disdrometer reflectivities. The slope is such that Z_p is larger than Z_J till about 20 dBZ, and smaller thereafter. Because this slope is more or less constant from low Z to high Z, it is difficult to ascribe this slope to any of the effects considered above. One possibility under consideration is the effect of under sampling caused by the small sample volume of the disdrometer. Recent theoretical work (e. g., Jameson and Kostinski, 2000; Smith et al., 1993) on this problem indicates that undersampled rain observations would be biased low. Because Z and rain rate are positively correlated, this might explain a continually higher (truer) estimate of Z_j as Z_j increases.

4. DISCUSSION AND SUMMARY

These results suggest that a vertically pointing profiler and a disdrometer collocated at a site with little radar clutter or acoustic noise may, at the current state of the art, be brought into agreement to within an order of plus or minus one dBZ for stratiform rain, and within a couple of dBZ for convective rain, provided tens of hours of one-minute observations are available.

We find that there is an optimum band of reflectivity factor (20 < Z_J < 30 dBZ) within which contaminating effects seem minimized. Even within this band there is a slope to the δZ versus Z_J line that is not well understood. This slope is of the order of 0.5 dBZ per decade of Z_J. That this may be an example of under sampling bias due to the small sampling volume of the disdrometer is a hypothesis currently under investigation. Another possibility might be a slight difference in drop shape between stratiform and convective rain events. Since the big drops occur mainly in the convective events, mixing the two categories could produce such a slope.

Examination of the vertical structure of the LBA data showed that, at least at this site, even convective rain might be used for calibration. However, more precision is achieved for the same number of observations in the stratiform case, and if the lower range gates are unusable for some reason, extrapolation to the surface is much better for the stratiform case. These observations are in line with Tokay et al., 1999, who explored the vertical structure of a number of classes of precipitation above Kapingamarangi Atoll in the tropical Pacific. They observed mean reflectivity gradients with height for all but stratiform and mixed stratiform/convective cases (their figures 9 to 11).

The S-band, or 2835 MHz profiler, was found to be less subject to contamination by Bragg scatter, and is therefore superior to the 915 MHz profiler with respect to the measurement of light rain. Nonetheless, it too may be contaminated for very light daytime rain, and perhaps a C- or X-band profiler should be considered to run along side the S-band. Echo attenuation by rain at these higher frequencies would be an issue.

Finally, we note that for calibration work we can, apparently, avoid some problems by considering a central range of Z. However, we do not have this luxury for general rain observations, and differences between the two instruments can be of the order of 2 dBZ for extreme low and high Z observations. It remains to identify the cause of this discrepancy.

5. ACKNOWLEDGMENTS

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