5.3 THE IMPORTANCE OF CROSS VALIDATION IN CLIMATE STUDIES: SELECTED CASE STUDIES OF RADAR/DISDROMETER REFLECTIVITY COMPARISONS

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1. INTRODUCTION

Although it is counterintuitive to many researchers because of the strong variability within precipitation processes, the accuracy achieved in the calibration of vertically pointing radars through comparison with a collocated disdrometer can be exceedingly precise (Gage et al., 2004). The absolute accuracy of the calibration, however, depends not only on the absolute accuracy of the disdrometer but on properly accounting for any effects that occur due to differences with respect to sample-volume location, size, and the time of sampling. The errors from these space-time mismatches are difficult to quantify and to explore their nature we are analyzing profiler/disdrometer reflectivity comparison data from four campaigns representative of a variety of locals. A chief finding from this analysis is the existence of a small, reflectivity dependent bias that is easily seen by plotting the differences in Z observed between the profiler and the disdrometer versus the reflectivity observed by either of the instruments. We find that the slope of this reflectivity dependent bias line seems to vary with the height of the range gate chosen for the comparison. This suggests that the bias may be due to changes in the DSD as rain falls the last few hundred meters to the surface. There is an extensive literature on the change of DSDs as rain falls, and it remains to see if this effect is adequate to explain the observed height dependence changes. Further work is also needed to document how these findings are related to stratiform vs. mixed vs. convective rain regimes.

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2. CAMPAIGNS

The observations in these case studies come from four profiler/disdrometer campaigns. Three of the campaigns occurred in support of the TRMM Ground Validation effort: LBA, 1999 in Brazil, TEFLUN B, 1998, in Florida, and KWAJEX 1999, 2000, and 2001. All three were tropical, with LBA being continental, TEFLUN B coastal, and KWAJEX maritime. The fourth site is at the NASA Wallops Island facility in Virginia and is temperate-coastal.

3. EXPERIMENT CONFIGURATION

The experimental setup at each site for the profiler calibration work was nearly identical. A 915 and/or 2835 MHz precipitation profiler was installed within 20 m of a Joss-Waldvogel disdrometer. As an example, Figure 2 shows the setup for the LBA campaign at Ji-Parana Municipal Airport in Brazil. For all three TRMM campaigns, the disdrometer and profilers were moved from site to site. At the Wallops site a different disdrometer was used and the 2835 MHz profiler has been upgraded by replacing the analog receiver with a new digital receiver. Also at this time the controlling software was changed from POP5 to LAPXM.

The profilers were set up to transmit and receive using a vertically pointing dish antenna so that, in the absence of strong horizontal wind, the disdrometer sampled precipitation that had fallen through the profiler sample volume. The same control computer logged data from the disdrometer and the profiler(s) during the TRMM campaign ensuring the sample times were synchronized on the minute. Because two pulse lengths alternated, the TRMM profiler observations consisted of 30 s means, not 1 minute means like the disdrometer. At Wallops a faster profiler cadence was used, so that s-band 7.5 s mean data is available every 15 seconds. The height resolution was also enhanced. The Wallops data were taken by alternating between 31 m and 62 m pulse lengths every 7.5 seconds while the TRMM data used here were taken using a 105 pulse that alternated every 30 s with a 250 m or 60 m pulse, depending on the site.

Figure 3 shows an example of a comparison during stratiform conditions taken at Kwajalein September 2-3, 1999, with a 915 MHz profiler. The band of high reflectivity near 5 km altitude is the melting layer. The DSD data observed by the disdrometer has been transformed to Z in dBZ for the comparison.

4. CALIBRATION

Since both a disdrometer and a collocated vertically pointing profiler, at least in the absence of strong horizontal wind, measure nearly the same precipitation, it would seem that one can use an accurately calibrated disdrometer to calibrate a profiler. Gage et al. (2004) have shown that although either the disdrometer or profiler's minute by minute mean observations of Z = 10log z have an associated Gaussian like error with a standard deviation of perhaps several dBZ, means of the differences between two independent and simultaneous measurements (i.e., measurements from two collocated and synchronized instruments) may be precise to exquisitely small values. An example of such comparisons is shown in Figure 4, where time series of simultaneous observations from two side-by-side disdrometers in the left panel and two side-by-side profilers in the right are presented.

Thus, if there are no systematic errors, the profiler and disdrometer can be brought into agreement to any desired precision simply by extending the set of observations to the necessary length. This technique is especially powerful because there is no need to work with just a single event, but an extended time series consisting of the concatenation of many events may be used to improve the precision. Figure 5 displays just such a data set, consisting of the s-band and disdrometer data for rain events that occurred throughout the LBA campaign (days 18-60, 1999, Ji-Parana, Brazil).

Figure 5 top panel shows the s-band reflectivity observations plotted against the Joss-Waldvogel (JWD) disdrometer observations. The bottom panel shows the difference between the two plotted against the disdrometer reflectivity. If the instruments were in perfect agreement except for the Gaussian noise fluctuations the points would all lie about the horizontal zero line in the bottom panel. But a close inspection shows that this is not quite the case. Looking at the yellow dots, which represent the median difference observed in 1 dBZ bins along the Z_{JWD} axis, we see there is a slight slope in the sense that the JWD appears to observe a higher Z value relative to the profiler as Z increases.

5. COMPARISON OF Z DIFFERENCE TRENDS BY CAMPAIGN

In order to easily compare the results from several campaigns, in Figure 6 we show the lines composed of median difference points found in 5 dBZ bins of Z_{JWD} (instead of the one dBZ bins represented by the yellow circles in the plot above). Note that we have set the median difference (i.e., difference between the profiler and the disdrometer) calculated between Z_{JWD} = 20 to 30 dBZ for each of these lines to zero since not all of these data sets had been calibrated in the same way. This focuses attention on the slopes. Although LBA, KWA, and TefB all have about the same slope, we see that the Wallops Island data is flatter. Although at first we thought this might be due to the fact that a different disdrometer was used at Wallops, the next figure (Figure 7) suggests a different explanation.

6. EFFECT OF ALTITUDE

In Figure 6 the data were all taken at different heights above the surface. Note that the heights are given in meters after the pulse lengths in the legend. This variety of altitudes happened with the TRMM observations because the sites had different clutter characteristics. The improvement in lowest useable height at the Wallops site, however, was due not only to a lack of clutter but an upgrade to the electronics, including replacing the analog receiver with a new digital receiver that allowed the use of a shorter pulse length and a greatly extended dynamic range. This allowed the lowest useable range gate at Wallops to be 50 m lower than at LBA and over 300 m lower than at Kwajalein. Comparing Figure 7 with Figure 6 shows the apparent effect of range gate height on the comparisons. In Figure 7 we have selected the range gate nearest 500 m for all sites. The slopes now appear to be fairly similar, which suggests that the main effect causing the slope is an actual change in the DSDs as the rain falls through the last few hundred meters to the surface.

7. DISCUSSION

A small Z dependent bias is observed in reflectivity comparison between precipitation profiler radars and Joss-Waldvogel disdrometers. This bias doesn't appear to be instrumental, but rather most likely due to height dependent changes in the DSD as rain falls the last few hundred meters to the surface. In the extreme, we find that when the lowest useable heights for calibration are several hundred meters or more above the disdrometer, a radar calibrated solely at extremely high reflectivity conditions could produce thereafter dBZ values up to 3 dBZ lower than those from a radar calibrated under extremely low reflectivities. This bias appears to be reduced to about 1 dBZ if heights only a hundred meters or so above the disdrometer are useable. There is an extensive literature on the change of DSDs as rain falls, and it remains to see if this effect is adequately explained there. Further work is also needed to document how these findings are related to stratiform vs. mixed vs. convective rain. We currently calibrate our profilers in the reflectivity range between 20 to 30 dBZ. This Z domain is located above the reflectivies associated with most Bragg scatter and emphasizes the stratiform over the convective. It will be necessary to understand the mechanism of this bias better to completely account for it, but this middle domain approach should ensure that our calibrations are within 1.5 dBZ or so of the true value. These results suggest that Z-R relationships should also vary systematically with altitude.

8. REFERENCES

Gage, K.S., W.L. Clark, C.R. Williams, and A. Tokay, Determining reflectivity measurement error from serial measurements using paired disdrometers and profilers, Geophys. Res. Lett., **31**, L23107, doi:10.1029/2004GL020591.

9. ACKNOWLEDGEMENTS

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10. FIGURES

Figures 1 thru 7 are on the following pages.

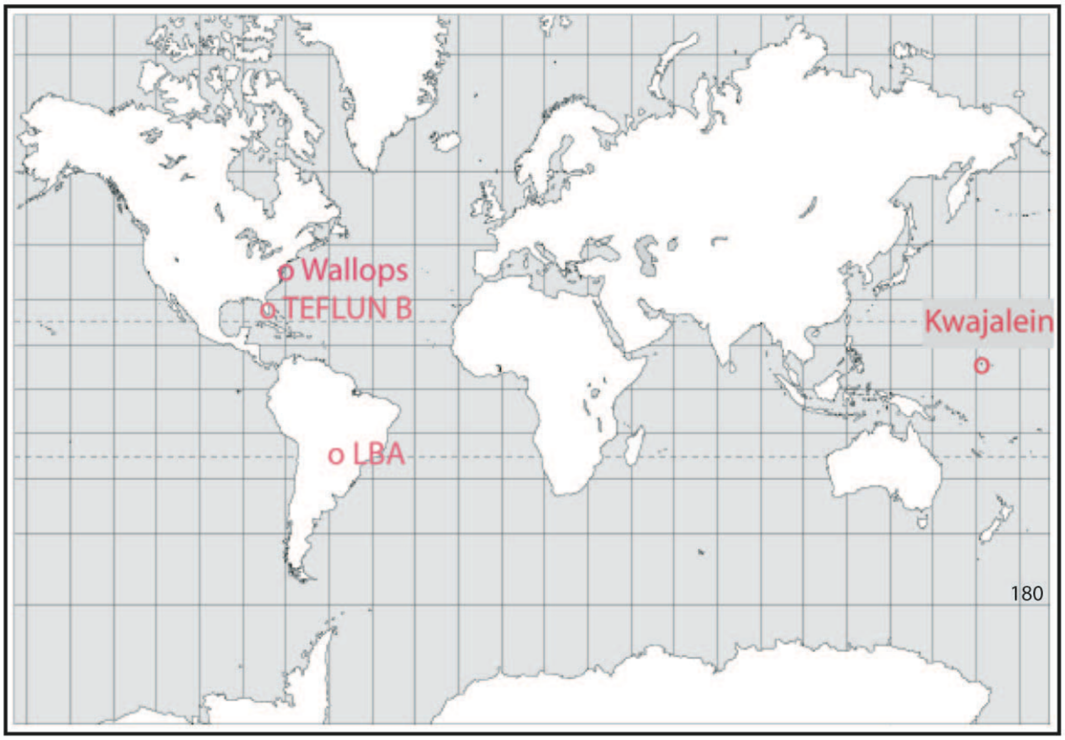

Figure 1: Geographic world map of the profiler/disdrometer sites used in this study.

Figure 2: From left to right are the radar control container, the 915 MHz profiler antenna shroud, the 2835 MHz antenna shroud, and the Joss-Waldvogel disdrometer in the right foreground, sitting on a tripod 1 m off the ground (Ji-Parana, Brazil).

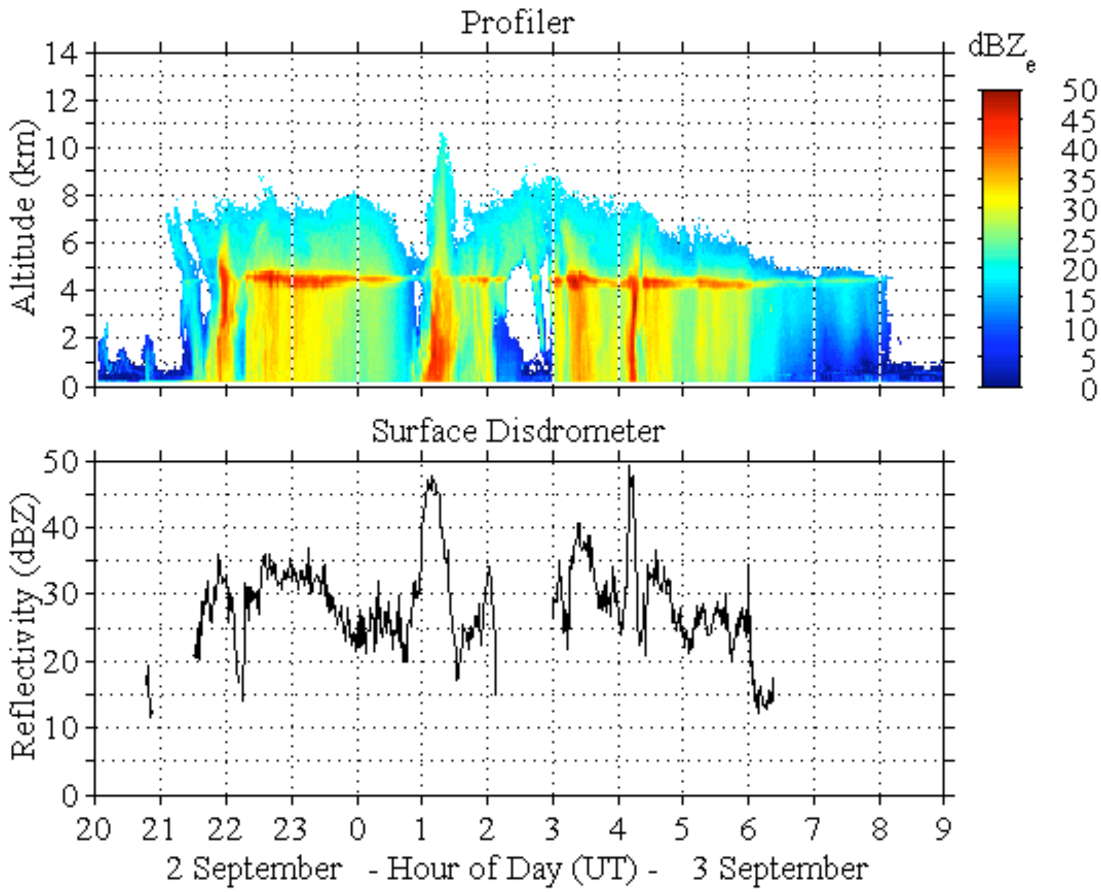

Figure 3: Example of the 915 MHz profiler time height display of Z at Legan Island in the Kwajalein Islands. The data are for September 2-3, 1999. A time series of the minute-by-minute Z values observed by a collocated Joss-Waldvogel disdrometer are shown in the bottom panel.

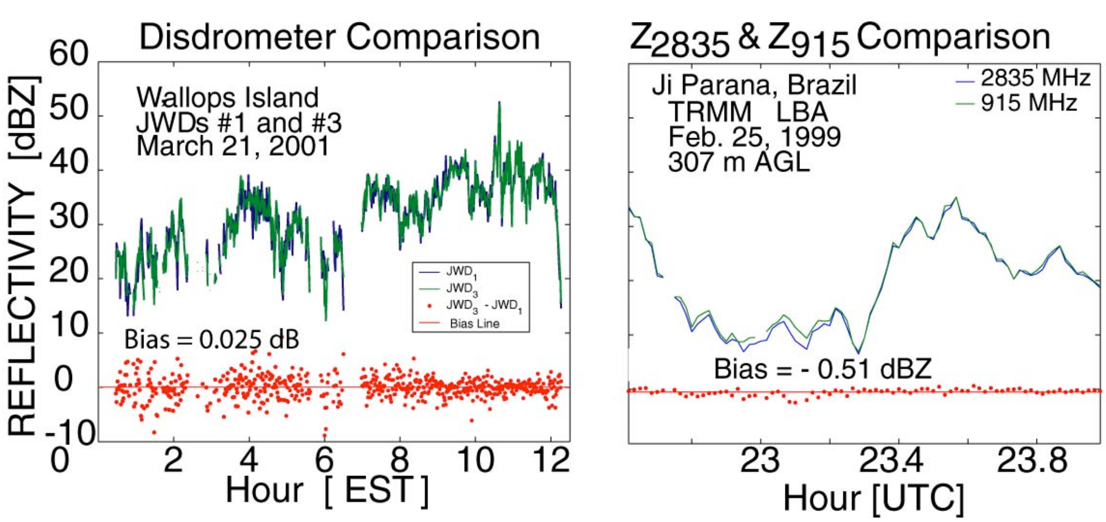

Figure 4: The left panel shows overlaid time series of the simultaneous observations from two collocated disdrometers. The red dots show the minute-by-minute differences between them. Although the minute-by-minute differences are large (standard deviation = ~3 dBZ) the 12 hour means differ by only 0.25 dBZ. The right hand panel shows a similar display for two collocated radar profilers, but at a different time and place. Here the 1 hour means differ by only 0.51 dBZ.

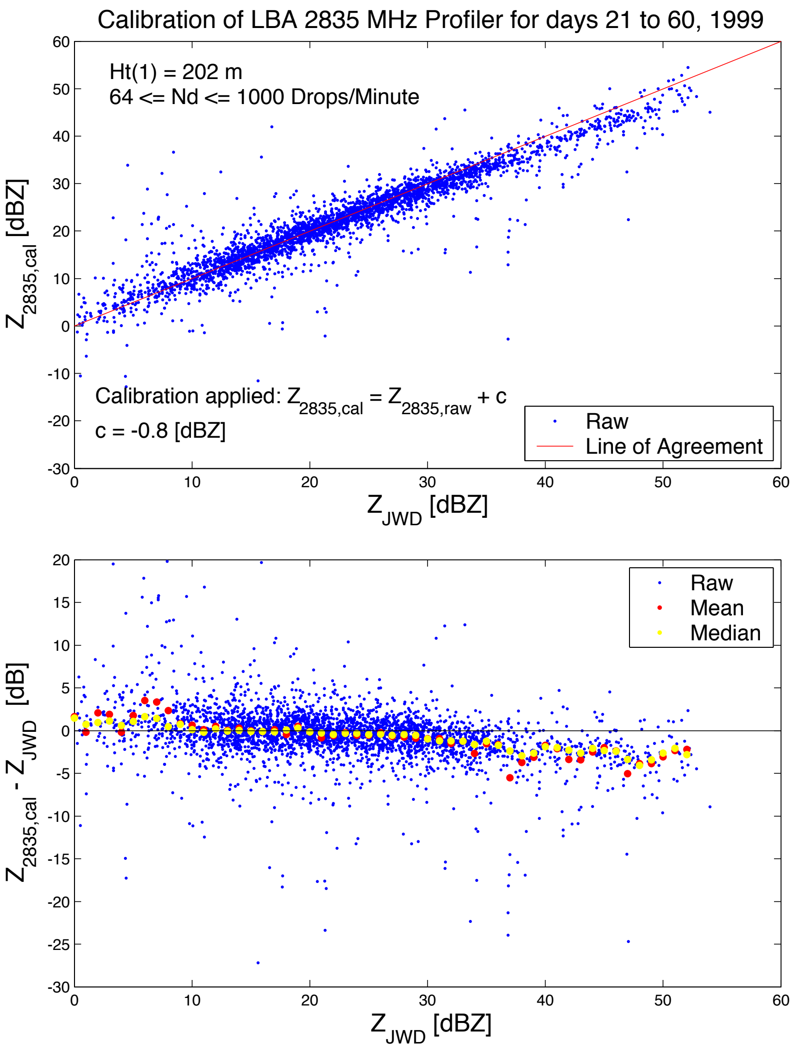

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Figure 5: The top panel shows a scatter plot of all the profiler/disdrometer reflectivity values for the 1999 LBA TRMM Ground Validation Campaign. This data utilizes the profiler range gate centered 202 m above the disdrometer. The red line is the line of agreement between the two instruments. It can be seen that they agree well up to about 30 dBZ on the x, or disdrometer, reflectivity axis. This is easier to see in the bottom panel where the differences between the two instruments are plotted along the y-axis. The yellow and red circles in this plot represent the mean difference found in bins centered on 1 dBZ steps along the disdrometer axis. The unexpected reflectivity dependent trend of the differences is the subject of this paper. We note in passing that the medians proved to be significantly more stable in this analysis, and hence have been used instead of the mean throughout.

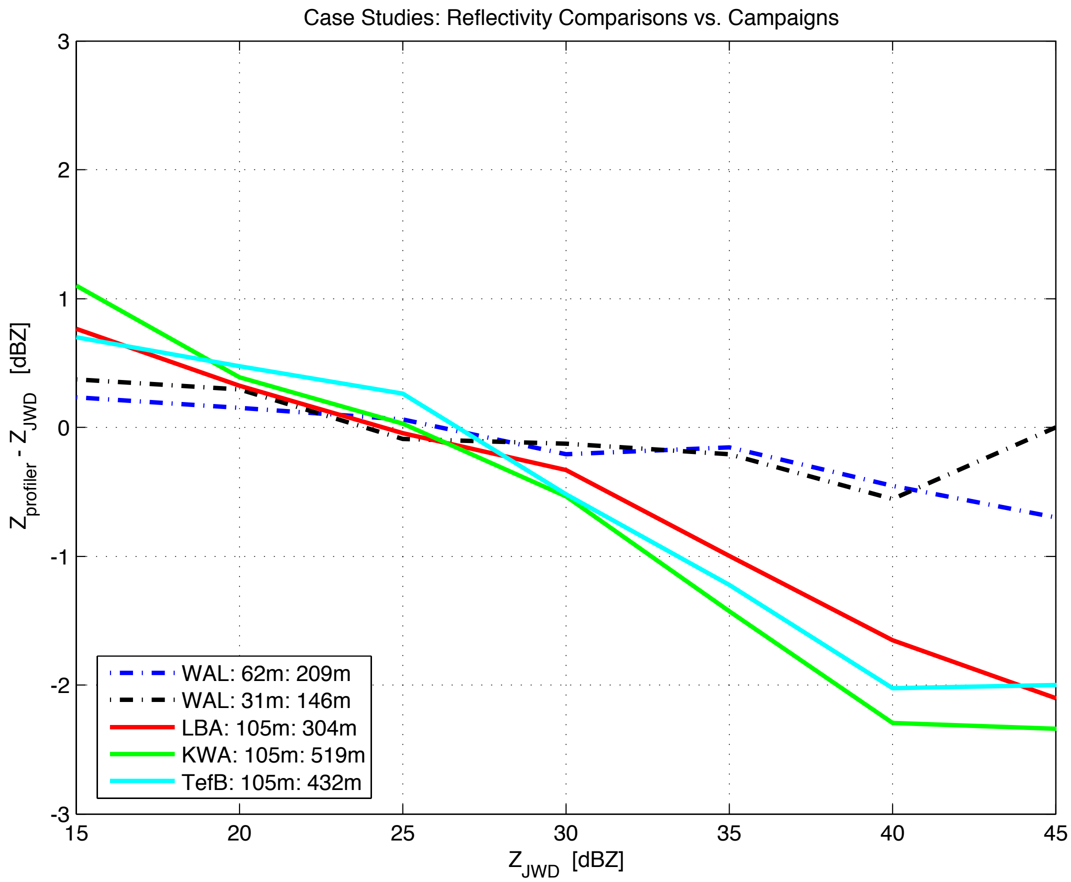

Figure 6: This figure shows the lines fit to 5 dBZ bin medians of reflectivity difference for all of the four sites studied here. Wallops has two lines, one corresponding to the 31 m pulse, and the other the 62 m pulse length. The height of the center of the first useable range gate at each site is given after the pulse length in the legend. The Wallops lines are noticeably flatter than those from the other sites.

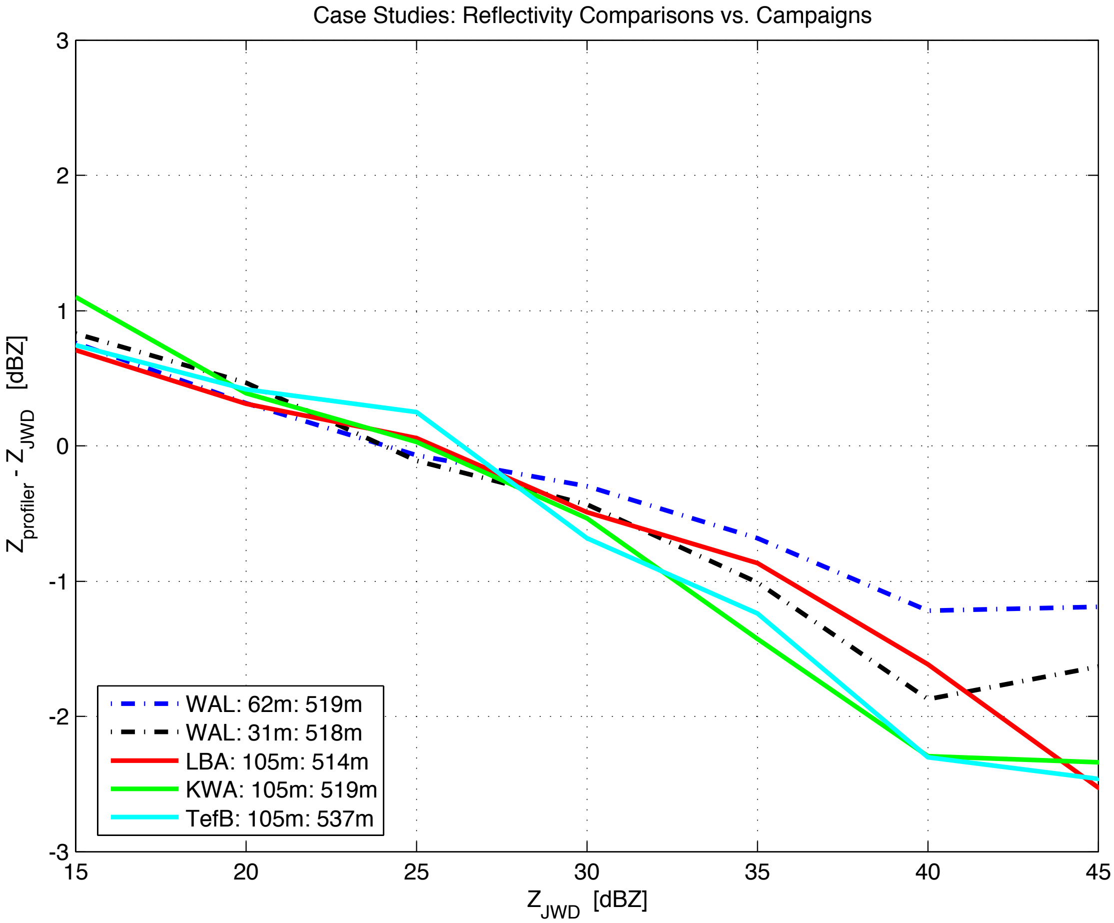

Figure 7: This figure is similar to Figure 6 except that here we used the closest range gate to 500m for all the stations. This high a height was used to match the Kwajalein data, where sea clutter made 500 m the lowest useable height. The slopes of the difference lines are now very similar for all sites. This suggest that the trend is due to changes in the rain drop size distribution as the rain falls through the last few hundred meters to the surface.