3R.1 USING GROUND CLUTTER TO ADJUST RELATIVE RADAR CALIBRATION AT KWAJALEIN, RMI

David S. Silberstein[1,2,*], D. B. Wolff[1,3], D. A. Marks[1,2], and J. L. Pippitt[1,2]

[1]NASA Goddard Space Flight Center, TRMM Satellite Validation Office, Code 613.1, Greenbelt, Maryland 20771
[2]George Mason University, Center for Earth Observing and Space Research, Fairfax, Virginia 22030
[3]Science Systems and Applications, Inc., 5900 Princess Garden Parkway, Lanham, Maryland 20706

1. INTRODUCTION

The ground radar situated on Kwajalein Atoll in the Republic of the Marshall Islands serves an important role in providing reflectivity measurements for comparison with rain gauge data collected and analyzed by the Tropical Rainfall Measuring Mission (TRMM) Ground Validation (GV) group at NASA Goddard Space Flight Center (GSFC) as well as satellite data obtained from TRMM. Radar calibration is a major source of uncertainty in radar rainfall estimation. Almost thirty years ago, Rinehart (1978) described a method for performing radar calibration checks using individual ground targets. GV staff attempted to perform an analysis using a single target, a tower situated on the island of Ebeye. The results of this single target procedure proved too noisy and a broader solution utilizing the entire clutter field at Kwajalein was sought.

The TRMM-GV group at GSFC developed a technique that incorporates the use of a clutter mask to denote radar pixels that are sources of frequent/permanent ground clutter. These pixels are used to generate probability distribution functions (PDFs) of reflectivity on a daily basis to assess the time evolution and stability of the calibration. The procedure and its consequences will be described in this paper.

*Corresponding author address: David S.Silberstein,TRMM Satellite Validation Office, NASA Goddard Space Flight Center, Code 613.1 Greenbelt, MD, 20771 email:silber@radar.gsfc.nasa.gov

2. METHODOLOGY

The TRMM GV group at GSFC is tasked with the generation of instantaneous rain rate estimates from the Kwajalein radar for comparison with satellite observations. In order to arrive at the most reliable estimates of rain rate, the GV team must address numerous sources of non-precipitation related reflectivity returns. One of these sources is ground clutter in the vicinity of the radar that can be generated by buildings and other physical structures. Beginning in 2000, GV staff visually identified areas of clutter by viewing sequences of radar images and by focusing on "hot spots" or high values of reflectivity in images otherwise devoid of meteorologically based echo.

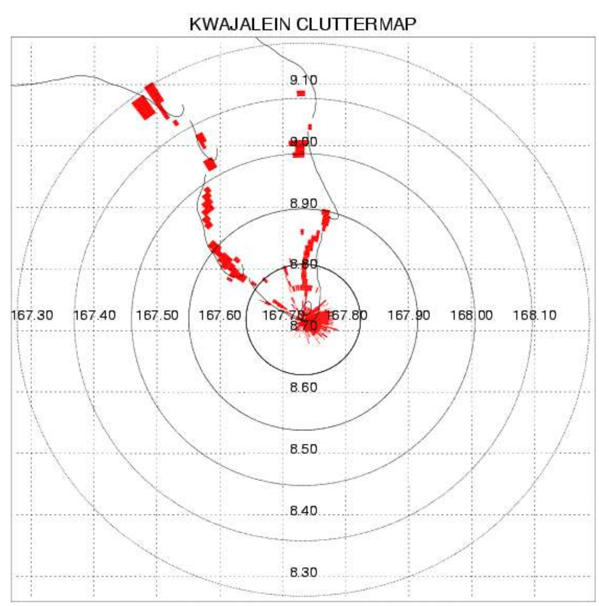

Figure 1. Map of the clutter field at Kwajalein. Range rings are drawn at 10 km intervals from the radar site.

These regions were identified according to range and azimuth from the radar and a database was built containing over 1300 range-azimuth pairs. This database was used to establish a clutter map, displayed in Figure 1, that can be used to eliminate the reflectivities associated with clutter in quality controlled versions of radar maps from Kwajalein. It is this clutter map of excluded locations in the estimation of rain rate which serves as the foundation for the data that is included in an investigation of the evolution of radar calibration.

The over 1300 range-azimuth pairs are from observations at one degree of azimuth and 1 kilometer spacing. As the radar completes a 360 degree sweep, for each degree of azimuth, reflectivities are recorded at individual gates which are spaced at approximately 264 meters. The specific data at each gate was extracted from the TRMM standard product 1C-51 data set in the Hierarchical Data Format (HDF). This product is described more fully in Wolff et al. (2005). The routines to perform the data extraction were written in the Interactive Data Language (IDL) based upon code developed for the Radar Software Library (RSL) in IDL set of routines. (Further information on RSL in IDL can be found online at http://trmm-fc.gsfc.nasa.gov/trmm_gv/software/rsl_in_idl/RSL_in_IDL.html) Since there are roughly four gates km^{-1}, this extraction provides nearly 5000 reflectivity measurements within the clutter region for a full sweep of the radar. During the course of a day, there can be up to 240 sweeps resulting in daily clutter data sets containing over 1 million entries. These daily collections of reflectivity values are the input for a series of PDFs from which a determination can be made about potential irregularities in the radar calibration. A sample of two daily PDFs from a period of relatively stable radar operation is displayed in Figure 2.

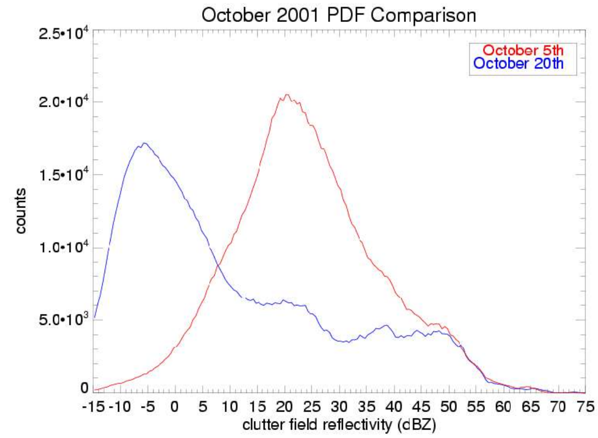

Figure 2. Comparison of two daily PDFs from October 2001

Once these daily PDFs are obtained, a decision must be made regarding the best way to isolate calibration effects from meteorological impact. Reflectivity values over clutter points may be influenced by precipitation related echo traversing the clutter field. A practical way to deal with this is to select an upper percentile of the cumulative distribution function (CDF) believed to be above the possible influence of real echo. The 95^{th} percentile of the CDF was selected to represent actual change in the calibration. A sample of two daily CDFs from October 2001 is displayed in Figure 3 for the same dates shown in Figure 2.

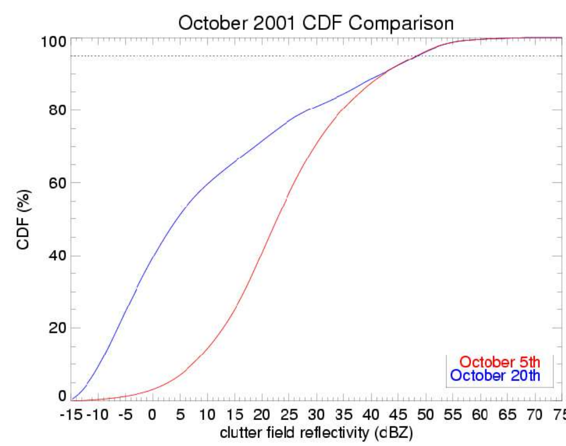

Figure 3. Comparison of two daily CDFs for the same dates displayed in Figure 2. The horizontal dotted line represents the 95^{th} percentile of the CDF.

Note that in Figure 3 the 95th percentile values for both days are nearly identical in spite of the fact that October 5 and October 20 featured very different meteorological conditions. Several organized rain bands traversed the field on October 5th while October 20th was a basically dry day with only a few scattered showers. In stark contrast to this October 2001 comparison, one of many periods of notable instability in the calibration was May of 2004. A plot of daily PDFs for consecutive days is displayed in Figure 4.

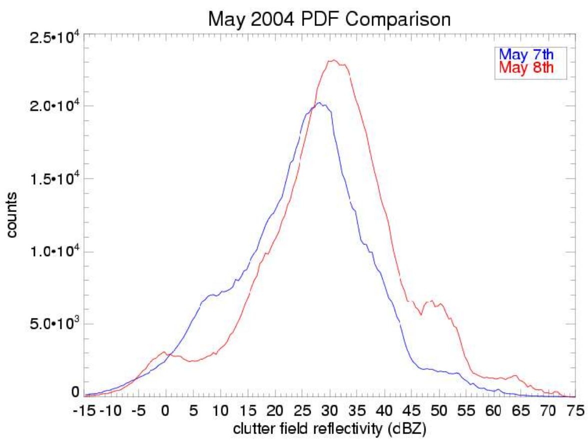

Figure 4. Comparison of two daily PDFs from May 2004

It is apparent from Figure 4 that there is a shift in the peak of the distribution toward greater reflectivities on May 8th. Of particular relevance is the substantial increase in counts for reflectivities from 50 to 70 dBZ, reflectivity intensities greater than one would associate with precipitation events at Kwajalein.

The CDFs associated with this May 2004 case are plotted in Figure 5.

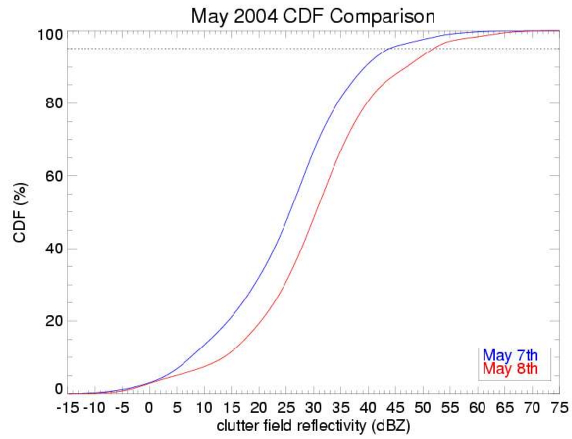

Figure 5. Comparison of two daily CDFs for the same dates displayed in Figure 4. Note the major discrepancy between 95th percentile values in contrast with the October 2001 case.

Figure 5 reveals the distinction between May 7th and May 8th over a wide range of reflectivities. Whereas in Figure 3 the 95th percentile values are nearly identical, there is a well defined increase in the 95th percentile of the CDF on May 8th . This increase is a clear signature of a calibration jump. The impact of this calibration jump can also be plainly seen in reflectivity images created from the raw data. Figure 6 is an image of the reflectivity field at 08 GMT on May 7, 2004.

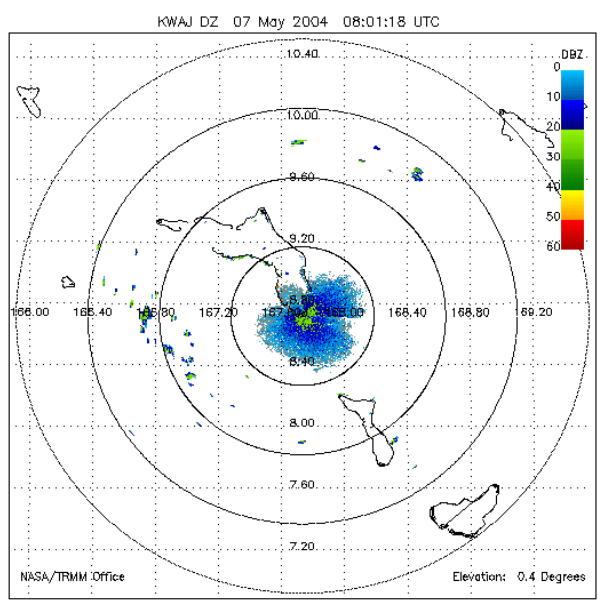

Figure 6. Raw reflectivity image for 08 GMT on May 7, 2004

Figure 7 depicts the raw reflectivity for the same time of day, 08 GMT, but one day later and following the calibration jump identified by the 95th percentile method.

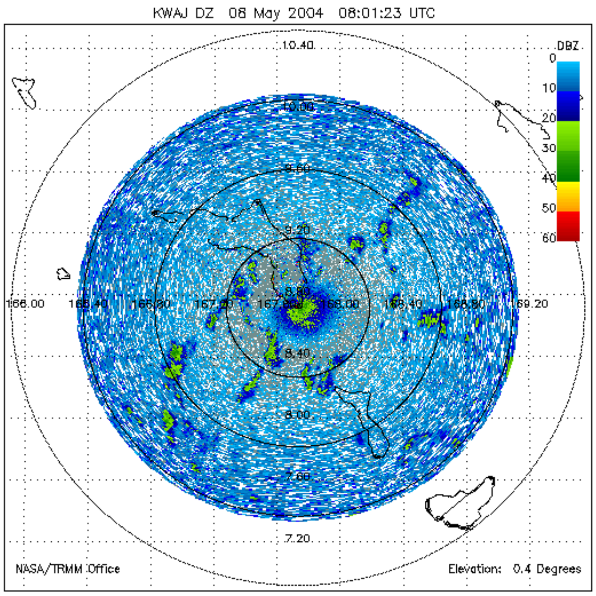

Figure 7. Raw reflectivity image for 08 GMT on May 8, 2004. The reflectivity scaling is identical to that applied in Figure 6.

It is evident from a comparison of Figures 6 and 7 that a major change has occurred in the interim. Not only are reflectivities higher in the clutter field but across the entire radar domain as well, an indication that whatever is happening within the clutter region is also affecting the rest of the radar scene. This particular calibration jump can be directly tied to a documented engineering change made on May 7th as the horizontal directional coupler loss was changed. The one day jump of 8.1 dB is one of the largest observed on consecutive days.

95th percentile values of the CDF of clutter field reflectivity were obtained for each day from August 1999 to the end of 2004. The result of this evaluation is plotted in Figure 8.

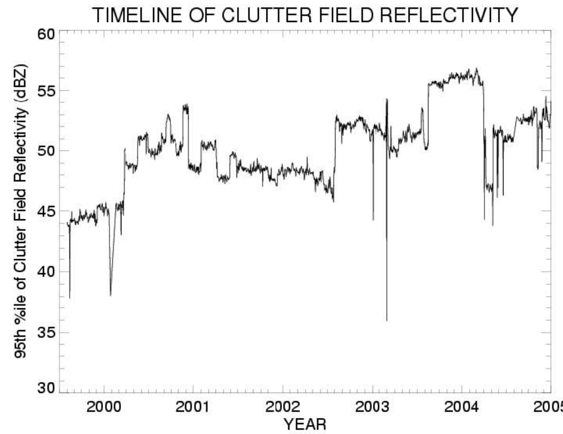

Figure 8. Time line of the 95th percentile of daily CDFs of clutter field reflectivity at Kwajalein

It is evident from examining Figure 8 that the 95th percentile of reflectivity undergoes major changes in the period from August 1999 to the end of 2004. There are minor daily fluctuations on the order of less than 1 dB as well as major variations on the order of several dB. GV staff reviewed the engineering logs from Kwajalein and in many cases, these major variations can be directly tied to the failure of key radar hardware or the replacement of faulty components. Several examples of specific engineering events are detailed by Marks et al. (2005). These direct relationships between time line behavior and engineering events provide some degree of confidence that the time line can capture calibration changes and that at these higher percentiles transient meteorological phenomena are not clouding the picture.

Merely having this time line is not in and of itself sufficient to provide a potential correction to the calibration. It is necessary to establish a baseline and that can only be done if there is a high degree of confidence in the calibration at a particular time. Fortunately, as a result of the intensive KWAJEX field campaign conducted in 1999 and subsequent collaboration among several institutions (NASA, Colorado State Univ., Univ. of Washington) there developed a consensus among researchers that during the month of August, 1999 the radar was running about 6 dB too low as compared with the TRMM precipitation radar (PR). With this knowledge, it is possible to establish a baseline by adding 6 dB to the 95th percentile value of August 1st, 1999 and making that summation the baseline reading to which all subsequent days would be judged. The original value on August 1 is 44 dBZ, therefore the baseline value is 50 dBZ. To calculate a relative daily calibration adjustment (RCA) , the daily 95th percentile value is subtracted from the baseline value. The result of this calculation for the period of August 1999 to the end of 2004 is plotted in Figure 9.

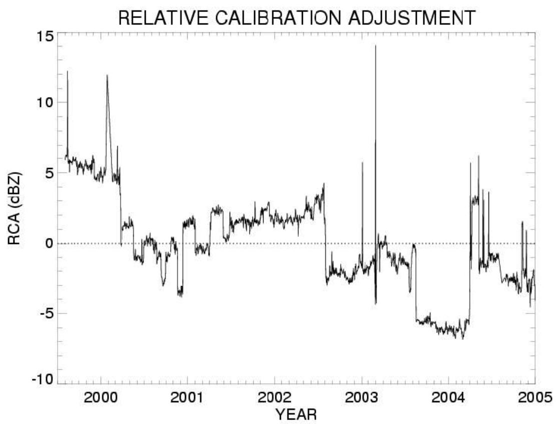

Figure 9. Time line of the relative calibration adjustment based upon the 95th percentile of the CDFs of clutter field reflectivity.

Daily RCA values can be directly applied to reflectivity values to correct for calibration inconsistencies. The implications of applying such corrections as well as caveats associated with this method are addressed in the following section.

3. IMPLICATIONS

The impact of these calibration adjustments on Kwajalein reflectivity is significant. The goal of TRMM-GV is verification of satellite estimates of rain rates. It is well established that a 1 dB variation in reflectivity can result in a 15 percent variation in the estimate of rainfall. For example, Houze et al. (2004) relate a $\pm$30 percent error in rain rate estimation to a $\pm$2 dB error in reflectivity which is consistent with our internal calculations. There is no rule for selection of the most ideal percentile of the CDF to create a time line of reflectivity adjustments. The selection of the 95th percentile was intended to isolate measurements of reflectivity unperturbed by meteorological events. Percentiles greater than the 95th were not chosen due to potential sampling and CDF curve interpolation issues. At this time, it is uncertain that the specific corrections applied to individual days represent the very best corrections available. What does appear certain is that this method is providing new and much more detailed insights into the temporal behavior of the Kwajalein radar. Initial comparisons of calibration adjusted reflectivities with TRMM satellite data are explored by Marks et al. (2005). Further study must be done to determine the impact of redefining reflectivity and whether this specific method is adequate to obtain the optimal result. These determinations will be difficult as other instrumentation quality issues, such as those affecting rain gauges at Kwajalein, introduce additional uncertainty into ground based comparisons.

4. SUMMARY

We have proposed a method for applying a relative calibration adjustment to reflectivity data at the Kwajalein radar site using the temporal evolution of a subset of the radar field consisting of defined clutter points. We believe that this procedure can be a benefit to researchers performing reflectivity and rain rate studies. Future work will examine further implications of reflectivity adjustment as well as potential applicability of the method to other radar sites.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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