EFFECT OF MICROWAVE RADIOMETER INTER-CALIBRATION ON RAINFALL ACCUMULATION FOR THE GLOBAL PRECIPITATION MEASUREMENT MISSION

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ABSTRACT

The effect of inter-calibration on a Level 3 rainfall product for the Global Precipitation Measurement (GPM) mission is examined using two spaceborne microwave radiometers that are currently used to derive rain measurements, the Tropical Rainfall Measuring Mission Microwave Imager (TMI) and the Special Sensor Microwave/Imager (SSM/I). It is found that inter-calibrating the microwave radiometer brightness temperatures from the two instruments improves the agreement of the derived rain accumulations between the two radiometers. The average difference between TMI and F13 derived rain accumulations is 0.60 mm/day before inter-calibration is applied. This difference decreases to 0.08 mm/day when F13 is inter-calibrated to TMI.

Index Terms—Microwave radiometry, Inter-calibration, Rainfall retrieval

1. INTRODUCTION

Spaceborne microwave radiometers are an important tool used to measure global precipitation. Since the instruments are onboard satellites, they are able to achieve measurements of precipitation over otherwise hard to reach areas compared to *in situ* instruments or ground radar (e.g. oceans). It is therefore imperative that the microwave radiometers be properly calibrated so that the precipitation derived from the radiometer measurements is accurate. Furthermore, if several radiometers are to be used to derive precipitation, such as in the Global Precipitation Measurement (GPM) mission, the radiometers need to be inter-calibrated to ensure that the precipitation derived from the various instruments is consistent [1]. The objective of the GPM X-Cal team is to develop algorithms to inter-calibrate the microwave radiometers used in the constellation for GPM [2]. These algorithms have been successfully applied to several current spaceborne microwave radiometers to calculate calibration differences between the radiometers, which are then applied to the brightness temperature (TB) measurements of the radiometers to make the TB measurements between different radiometers consistent with each other. Inter-calibration adjustments are based on the TBs and not the derived precipitation products in order to minimize their dependence on any model assumptions that may be incorporated into the precipitation retrieval algorithms.

It is not well understood what, if any, effect the inter-calibration has on the derived precipitation products for GPM. Since the inter-calibration of the TBs is done to make the measurements, and thereby the derived products, more consistent with each other, this is an important analysis to be done. This paper will examine the effect of microwave radiometer inter-calibration on one of the precipitation products that will be produced for GPM.

2. RAIN RETRIEVAL ALGORITHM

The predecessor for the GPM mission, the Tropical Rainfall Measuring Mission (TRMM), is currently on orbit and has several rain products that are derived using the Precipitation Radar (PR) and the TRMM Microwave Imager (TMI) onboard the spacecraft. Since we are concerned here with the effect of the inter-calibration of the microwave radiometers on the rain retrievals, we will examine the products that only make use of the radiometer data. One of these is the Level 3 3A11 product that gives monthly rainfall accumulations. This will be used as an example here. The 3A11 product operates directly on the Level 1 microwave radiometer TBs to produce monthly rainfall accumulations over the ocean for 5° latitude/longitude gridded regions [3]. This retrieval algorithm will hereafter be referred to as the WCC algorithm. The WCC algorithm was developed for the Special Sensor Microwave/Imager (SSM/I), but has since been adapted for TMI. It makes use of the 19 GHz and 22 GHz vertically polarized (V-pol) channels to derive the rain accumulations. Monthly histograms of the radiometer TBs are generated for these two channels for each 5° grid box, and the freezing level is calculated using a radiative transfer model. This freezing level is then used with the histogram of a combined channel, $2*TB_{19V} - TB_{22V}$, to derive the monthly rain accumulations in mm/day. A full description of the WCC algorithm is given by Wilheit et al. [3].

The goal of this study is to quantify the effect that inter-calibrating the microwave radiometers has on the Level 3 rainfall accumulations derived using the WCC retrieval algorithm. A comparison is made between the derived rain accumulations using the TBs with inter-calibration applied versus the unadjusted TBs. SSM/I and TMI are two radiometers currently being used by the X-Cal team to develop inter-calibration algorithms and will be used as examples in this study.

3. INTER-CALIBRATION ALGORITHM

The inter-calibration algorithm developed for the GPM mission consists of two calibration differences; one is found at a cold TB and the other at a warm TB. These calibration differences are considered to be the TB offset between the two radiometers being inter-calibrated at those respective temperatures. A warm and cold TB difference is found since the calibration is not considered constant at all brightness temperatures. Instead, a linear relationship between the cold and warm TB differences is used. One way to calculate the calibration difference at the cold end is to use vicarious cold calibration [4]. This is used as an example here. The warm calibration difference is found using vicarious warm calibration [5].

Table 1 shows the cold and warm calibration differences for SSM/I F13 and TMI found using the inter-calibration algorithms described above for those channels associated with the WCC algorithm. The differences are given as F13 – TMI. Both a calibration difference and the temperature at which this difference is found is given, so that a linear interpolation can be performed between these two ends to find the calibration differences at all brightness temperatures. For the purpose of this study, F13 is adjusted 100% to TMI. TMI is not considered truth here; it is merely the reference to which F13 is compared in a relative, rather than absolute, sense. Because of the low-inclination orbit of its platform, TMI crosses the orbits of all of the other GPM constellation radiometers creating many coincident match-ups between these other radiometers and TMI. As such, it makes a convenient relative reference. The purpose of this study is to compare the differences between the derived rain from TMI and F13, not to derive an absolute rain accumulation value.

	19V	22V
Cold Difference (K)	1.3	2.2
Cold Temperature (K)	182	192
Warm Difference (K)	0.6	3.9
Warm Temperature (K)	285	284

Table 1: Cold and warm calibration differences for TMI and SSM/I F13. Differences are given as F13 – TMI.

4. RESULTS

The WCC algorithm is first applied to the TMI and SSM/I F13 TBs monthly from July 2005 – June 2006 without inter-calibration applied. Figure 1 gives an example of the global accumulated rain for July 2005 for TMI and F13. Since SSM/I is on a sun-synchronous orbiter, the total rain accumulation is calculated by deriving the rain for the ascending (night) and descending (day) orbits separately and then averaging the two results to get the final rain accumulation for the month. The WCC algorithm for TMI does not distinguish between ascending or descending nodes of the satellite. Also, since TMI is in an orbit with a 35° inclination, the radiometer only observes those latitudes roughly between -40° and +40°, so the F13 observations outside this latitude range are not used. It is clear from Figure 1 that TMI and F13 retrieve similar global rain features, but TMI on average retrieves higher rain accumulations than F13, most notably along the Inter-Tropical Convergence Zone (ITCZ).

Figures 2 and 3 show comparisons between the TMI and F13 rain accumulations for the entire year with no inter-calibration applied. Figure 2 is a zonal mean of the rain accumulation difference between F13 and TMI, and Figure 3 is a comparison between F13 and TMI derived rain. Each point in Figure 3 is associated with one 5° grid box. From Figure 2, it is evident that the greatest differences in the rain accumulation occur near the equator at the ITCZ, which is where the heaviest rain is concentrated (as seen in Figure 1). Figure 3 also shows that F13 and TMI differ the most for high rain amounts. The strength of the ITCZ varies depending on the season, and therefore the difference between rain accumulations of TMI and F13 also changes with the season.

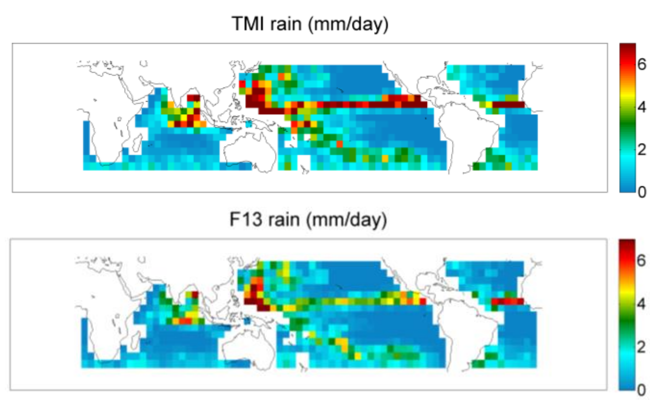

Figure 1: July 2005 rain accumulation for TMI (top) and SSM/I F13 (bottom).

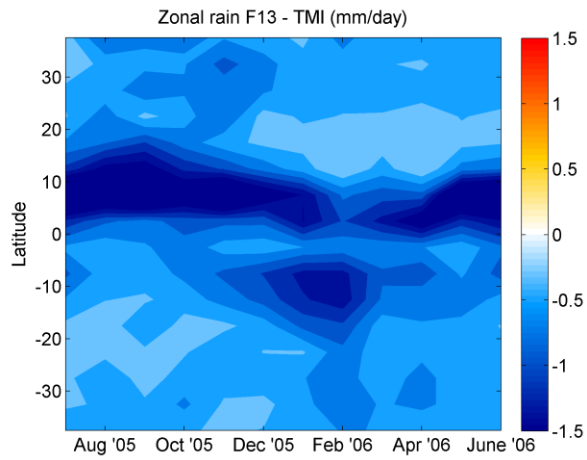

Figure 2: Zonal mean difference of rain accumulations for SSM/I F13 – TMI from July 2005 – June 2006. The greatest difference in rain occurs near the tropics.

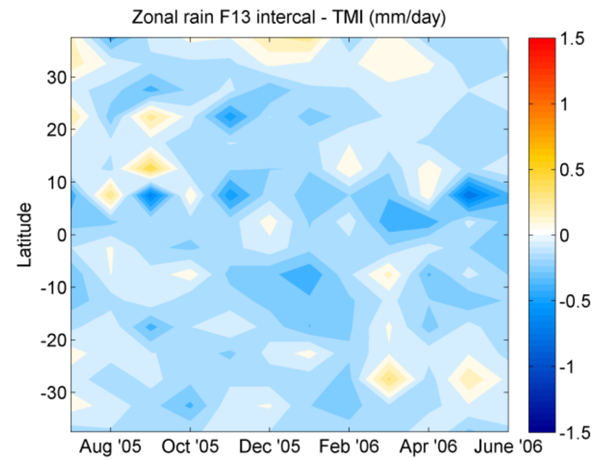

Figure 4: Zonal mean difference of rain accumulations for inter-calibrated F13 – TMI from July 2005 – June 2006. The large difference in the tropics has been greatly reduced.

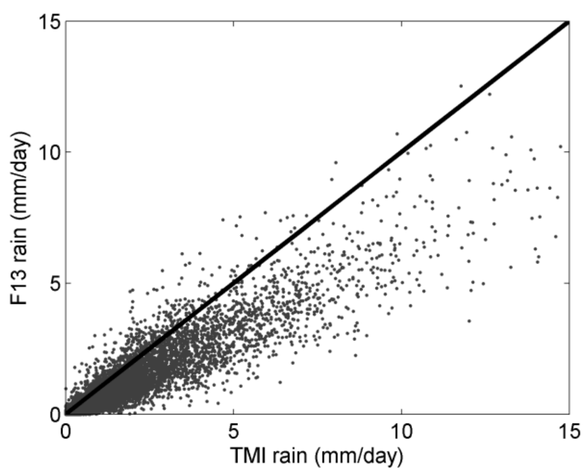

Figure 3: SSM/I F13 rain accumulation versus TMI rain accumulation. The black line is the 1:1 line. TMI generally retrieves higher rain accumulation values than F13.

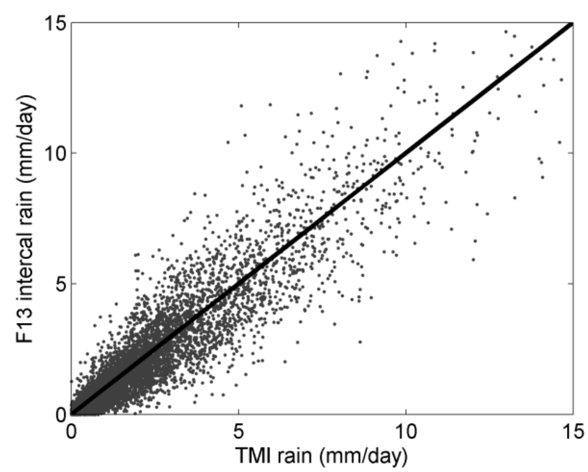

Figure 5: Inter-calibrated F13 rain accumulation versus TMI rain accumulation. The black line is the 1:1 line. The rain accumulations agree better when F13 is inter-calibrated to TMI.

The inter-calibration differences from Table 1 are applied to the SSM/I F13 19 GHz and 22 GHz V-pol TBs to adjust the F13 TBs to TMI. The WCC algorithm is then performed on the adjusted TBs for F13. The results of the comparison to the TMI derived rain are shown in Figures 4 and 5. There is a significant improvement in the agreement between F13 and TMI rain accumulations. The large difference at the ITCZ has nearly disappeared and the F13/TMI rain accumulation comparisons lie more along the 1:1 line as seen in Figure 5.

5. ANALYSIS

Using all grid boxes for the year of rain accumulations, the difference between the average rain accumulations of F13 and TMI is 0.60 mm/day, while the difference is only 0.08 mm/day after F13 is inter-calibrated to TMI. Performing a linear regression on the data from Figure 3 gives a scale of 0.64 and offset of 0.05 for the F13 versus TMI rain accumulations. When F13 is adjusted to TMI through inter-calibration (Figure 5), the scale becomes 0.96 and the offset -0.01, which shows that inter-calibration greatly increases the agreement between the TMI rain and F13 rain.

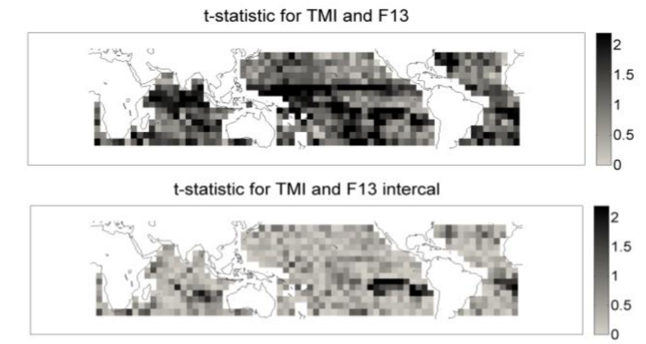

Figure 6: t-statistic values for TMI/F13 (top) and TMI/F13 inter-calibrated (bottom). 12.4% of grid boxes reject the null hypothesis for F13 unadjusted, while only 1.3% reject it when F13 is inter-calibrated to TMI.

A paired t-test is used to compare the mean rain accumulations from TMI with F13 with and without inter-calibration applied. A similar test was performed by Chang et al. to compare rain accumulations from SSM/I and TMI [6]. The null hypothesis for the test is that the mean difference between TMI and F13 rain accumulations is 0. A t-test is performed on each 5° latitude/longitude grid box for the 12 months of rain accumulations. Figure 6 shows the t-statistic results of this analysis for F13 (top) and F13 inter-calibrated to TMI (bottom). For 11 degrees of freedom (12 months of rain accumulations), a t-statistic greater than 2.20 means there is a statistically significant difference between the TMI and F13 rain accumulations with 5% significance, and the null hypothesis is rejected. For F13 without inter-calibration, the percentage of grid boxes that reject the null hypothesis is 12.4%, while only 1.3% of grid boxes for F13 with inter-calibration applied reject the null hypothesis. Figure 6 also shows that overall, the t-statistic for F13 inter-calibrated is lower than that without inter-calibration applied. This analysis further confirms that inter-calibrating F13 to TMI increases the consistency of the rain accumulations derived from each radiometer.

6. CONCLUSION

Inter-calibration of microwave radiometers was shown to be necessary if rain measurements from one radiometer are to be compared to another. Using a Level 3 rain retrieval algorithm, it was shown that by first adjusting the SSM/I F13 TBs to agree with the TMI TBs, the relative accuracy of the derived rain accumulations was greatly increased. This study confirms the hypothesis that if different radiometers are to be used to derive precipitation, such as for the GPM mission, it is necessary to first make the TB measurements agree; otherwise the derived rain will not be consistent. Future plans are to examine the effect of microwave radiometer inter-calibration on a Level 2 retrieval algorithm that gives instantaneous rain rates.

7. REFERENCES

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