ROBUSTNESS OF THE VICARIOUS COLD CALIBRATION ALGORITHM IN THE DOUBLE DIFFERENCE METHOD FOR GPM INTER-CALIBRATION

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ABSTRACT

The robustness of the double difference method used for inter-calibration of microwave radiometers in the Global Precipitation Measurement (GPM) mission is analyzed. The double difference provides a way to compare two different radiometers and is more accurate than just a direct comparison. This is due to the double difference being able to remove geophysical variability from a radiometer's data, as well as frequency and incidence angle dissimilarity between radiometers that would otherwise get included in a direct comparison. These variations are removed by incorporating radiometer modeled brightness temperatures into the inter-calibration process using a vicarious calibration technique. This analysis shows how well the modeled radiometer data is able to remove these variations as well as how well the double difference method performs compared to a direct radiometer comparison.

Index Terms— Microwave radiometry, Calibration

1. INTRODUCTION

The Global Precipitation Measurement (GPM) mission is an international multi-satellite mission that will measure precipitation from space [1]. The GPM mission is unique in that it will utilize several different microwave radiometers on individual satellites to provide global coverage of precipitation measurements. This use of multiple satellites brings up the issue of inter-calibration among the radiometers, since the individual instrument characteristics of each radiometer must be accounted for in order to compare measurements from each. Three forms of calibration that are used in the method of inter-calibration for GPM will be explored here. The first is a direct calibration, which consists of using a vicarious reference as a calibration point for the radiometer. The second form is a single difference. This method uses the vicarious calibration reference point from a radiometer's observations and compares it to a reference point from simulations. These simulations are modeled brightness temperatures (TBs) that reflect what the radiometer should observe. The single difference is then just the difference between the reference points of the observations and simulations. The third form of calibration that will be looked at is the double difference. The double difference is found by taking the difference between the single differences of two radiometers, which provides a way to inter-calibrate the radiometers.

The vicarious calibration technique is used to provide both cold [2] and warm [3] reference points for radiometer observations. The vicarious cold calibration uses the theory that the coldest TB that a microwave radiometer would observe is over the ocean with calm surface winds, no clouds, and minimal water vapor. The vicarious warm calibration uses the Amazon rainforest as a warm reference point since it best approximates a blackbody target due to its heavy vegetation.

In order to achieve an accurate inter-calibration for GPM, we want a statistic that is stable. The purpose behind the double difference is that it should be more stable and accurate than just directly comparing two radiometers. This stability essentially comes from the single difference. The performance of the three forms of calibration for the cold end will be examined here to show the advantage of the double difference. The sensitivity of each type of calibration to various ways in which the radiometer data are sampled will be analyzed. The data can be sampled spatially, by splitting the data up by latitude or location on the globe, or temporally, by dividing the data into seasons or by month. Sampling the data this way provides a way to monitor the performance of the radiometer just in certain months or regions of the globe, so it is important to know how the inter-calibration algorithm behaves in these cases.

The Advanced Scanning Microwave Radiometer (AMSR-E) and the Tropical Rainfall Measurement Mission Microwave Imager (TMI) are two of the radiometers currently being used for GPM inter-calibration algorithm development [4]. These radiometers will be used as examples in this study.

2. INTER-CALIBRATION ALGORITHM DESCRIPTION

Direct calibration consists of using the vicarious cold calibration technique to find a cold reference TB (called the 'cold cal TB') from radiometer observed TBs. The single difference makes use of the cold cal TB from the observations and compares it to a cold reference TB calculated from simulations. These simulations are top of atmosphere TBs that are generated using a radiative transfer

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model (RTM) with inputs from the Global Data Assimilation System (GDAS) [5]. The inputs from GDAS include atmospheric and surface parameters such as sea surface temperature, surface wind speed, and profiles of temperature and relative humidity. These parameters are given every six hours over the entire globe at 1° latitude/longitude intervals. The simulated TBs from the RTM are created using frequencies and earth incidence angles (EIAs) that correspond to the radiometer of interest. The RTM is run at the same latitude/longitude (averaged to 1°) and time (to the nearest six-hour interval) as reported in the radiometer data to ensure that the simulated TBs are statistically similar to the observed TBs. The coldest TBs occur for calm ocean with no clouds and minimal water vapor, and these conditions are relatively straightforward to simulate. Therefore, the simulations should be able to model very closely what the radiometer observes.

The cold cal TB is computed from histograms of the TB population for a given time period and geographic region for both the observations and simulations, and the difference between these values is found. This is called the single difference. The same process is then repeated for a different radiometer, and the difference between the two single differences is calculated. This gives a final number called the double difference, as shown in Equation 1 for two arbitrary radiometers *A* and *B*.

$$DD = \left(TB_{cold}^{A,obs} - TB_{cold}^{A,sims}\right) - \left(TB_{cold}^{B,obs} - TB_{cold}^{B,sims}\right) \qquad (1)$$

The double difference method provides a more stable way of inter-calibrating than just directly comparing two radiometers. Direct comparison does not take into account differences in radiometer frequency and EIA, nor does it account for variations in the cold cal TB that are environmental in nature and not instrumental. The double difference can account for these.

3. SENSITIVITY STUDY

The performance of the direct calibration, single difference, and double difference approaches are examined by first giving an example of the sensitivity of the direct calibration cold cal TB to geophysical variations. Next, the single difference is shown to be able to remove this geophysical variability in the direct calibration, as well as any EIA variation. Finally, the double difference performance is analyzed and is shown to be more accurate than doing a direct comparison between two radiometers.

3.1. Direct calibration

Water vapor in the atmosphere naturally fluctuates throughout the year due to seasonal changes. While the cold cal TB minimizes the impact of water vapor, it does not eliminate it. This is especially true of the water vapor channel on the GPM radiometers. Figure 1 gives an example of how the cold cal TB changes over a year for the AMSR-E 23.8 GHz vertically polarized channel. In order to see this seasonal variation, AMSR-E observed TBs are sampled by month and location on the globe. The vicarious cold calibration algorithm is then used to find the cold cal TB for each month and region to observe the seasonal cycle. Figure 1 shows the cold cal TB sampled in three regions: the Northern Hemisphere (NH), the Southern Hemisphere (SH), and the globe (both NH and SH).

One way to quantify the seasonal variation in the cold cal TB is to take the difference between the yearly maximum and minimum cold cal TB values. The greater this difference between the maximum and minimum cold cal TBs, the more sensitive that sample set of data is to geophysical variability. This provides a performance metric for the sensitivity of the direct calibration that can also be used for the single difference and double difference. In this case, the max/min difference for the globe, the NH, and the SH direct calibration is 1.57 K, 8.67 K, and 1.93 K, respectively.

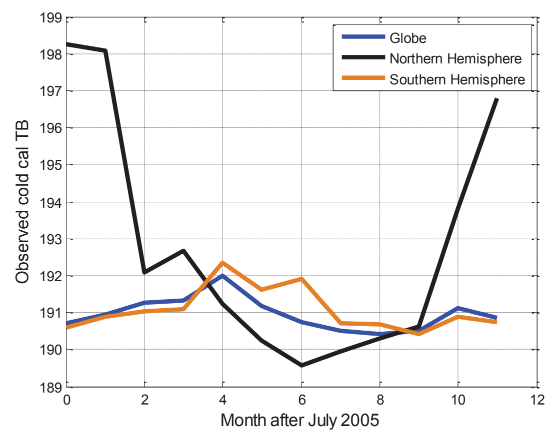

Figure 1: AMSR-E 23.8V GHz observed cold cal TB over a year for the globe, NH, and SH.

3.2. Single difference

In order to remove the seasonal variability in the cold cal TB so it is not included in inter-calibration, the simulated TBs are used to difference out this effect in the single difference. Figure 2 gives an example of how well the single difference is able to remove geophysical variability in the cold cal TB. The data are from AMSR-E 23.8V GHz observations and simulations for just the NH since the NH displays more variability in the cold cal TB than the SH as seen in Figure 1. The max/min difference for the direct calibration is 8.67 K, while the max/min difference of the single difference is just 1.29 K. The single difference clearly takes care of most of the seasonal variability that is observed when just performing the direct calibration by itself.

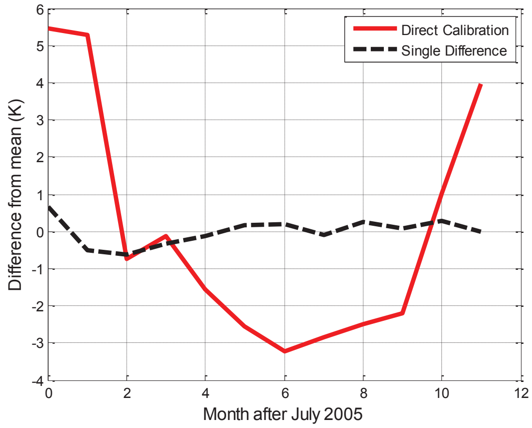

Figure 2: Comparison of AMSR-E direct calibration and the single difference for the NH.

It is also important to note how the cold cal TB changes as a function of latitude. This is significant for a number of reasons. First, some radiometers, like TMI, have low inclination orbits and therefore do not observe the higher latitudes where the coldest TBs occur. Also, since EIAs can vary as a function of latitude due to eccentricity in the satellite orbit and the oblateness of the Earth, the cold cal TB will change as a function of latitude. Table 1 shows some results from this study where the AMSR-E data is sampled by latitude every 10°. The max/min difference over one year is given for the direct calibration and the single difference, as well as the percent the max/min difference is decreased with the single difference. It is apparent that if the latitudes are limited, the geophysical variability in the direct calibration increases, at least for the latitudes where there is a large amount of water vapor fluctuation throughout the year. The single difference has a larger max/min difference for the low latitudes compared to the higher latitudes; however, the single difference is still able to remove a significant percentage of the seasonal variability.

Since the cold cal TB also varies as a function of EIA, the single difference needs to be able to remove this EIA variation. One way to see the dependence on EIA is to look at the cold cal TB across the scan. AMSR-E and TMI are both conical scanning radiometers, and EIAs can vary across the scan if there is a satellite attitude offset. Deviation from the nominal EIA impacts the cold cal TB [6], so it is very important to be able to model this in the simulations.

Figure 3 shows an example of how the cold cal TB varies across scan for the AMSR-E 10.65V GHz channel. This channel is chosen in order to have minimal geophysical effects, so that the main influence on the cold cal TB is just EIA. The observed cold cal TB and single difference is plotted for SH descending orbits only. There is a clear increase in the observed cold cal TB across the scan, which is mainly due to EIA variation across the scan as shown in Figure 4. The single difference shows that the simulations are able to model this trend and remove the EIA variation.

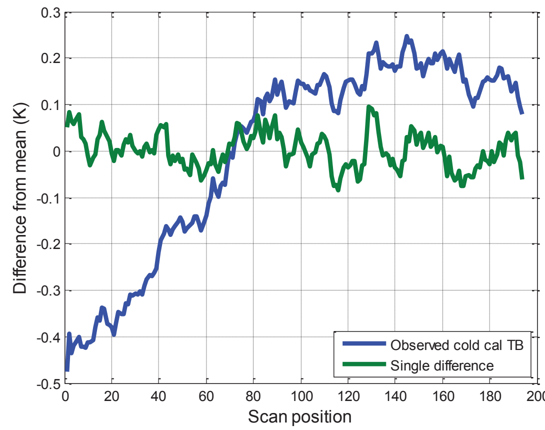

Figure 3: Observed cold cal TB and single difference across scan for AMSR-E 10.65V channel SH descending orbits only.

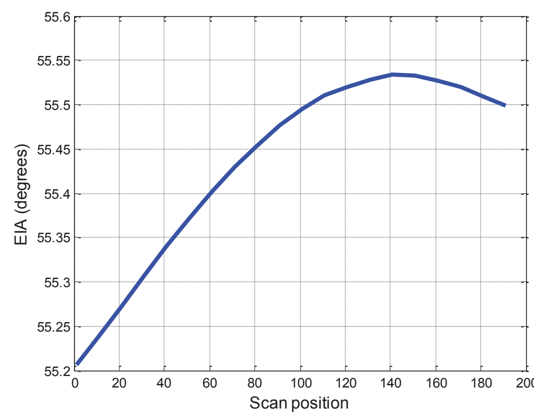

Figure 4: Scan dependent EIAs for AMSR-E SH descending orbits.

Latitude bin	-70° to -60°	-60° to -50°	-50° to -40°	-40° to -30°	-30° to -20°	-20° to -10°	-10° to 0°
Direct calibration max-min (K)	2.65	4.15	3.70	7.25	8.97	19.83	16.88
Single difference max-min (K)	1.67	1.31	1.29	1.48	4.08	5.09	3.94
Percent decrease in max-min (%)	37.0	68.4	65.1	79.6	54.6	74.4	76.7
Latitude bin	0° to 10°	10° to 20°	20° to 30°	30° to 40°	40° to 50°	50° to 60°	60° to 70°
Direct calibration max-min (K)	12.04	14.61	22.53	21.28	12.41	9.07	9.65
Single difference max-min (K)	4.23	2.96	5.17	2.60	2.12	1.73	1.14
Percent decrease in max-min (%)	64.9	79.7	77.1	87.8	82.9	81.0	88.2

Table 1: Performance of the direct calibration cold cal TB and the single difference when the data is split into latitude bins. The value reported is the difference between the maximum and the minimum values over 12 months.

3.3. Double difference

Once the single difference has been used to minimize geophysical effects in the cold cal TB, the double difference can be used to calculate the calibration difference between two radiometers. As an example of this, the double difference method is performed on a year of data for AMSR-E and TMI and compared to just directly taking the difference between AMSR-E observed cold cal TB and TMI observed cold cal TB. Using data from the whole globe for both orbits, the double difference gives a value of 1.26 K while the direct calibration gives a value of 3.21 K. The error in doing the direct calibration can be quantified by comparing the simulations from AMSR-E and TMI. The simulations take into account any frequency and EIA differences between the radiometers, as well as any geophysical effects. The difference between the simulated cold cal TBs from each radiometer should then be the error associated with not doing the double difference. Figure 5 shows this error, as well as the value of the double difference, by month. The double difference is fairly flat across all months, but the direct comparison has a large error associated with it in certain months. This large error is most likely due to water vapor effects and the fact that AMSR-E and TMI have different water vapor channels. AMSR-E's water vapor channel is 23.8 GHz with a nominal EIA of 55°, while TMI's water vapor channel is 21.3 GHz with a nominal EIA of 52.8°. Brightness temperature is very sensitive to frequency around the water vapor line, and so any small change in frequency or EIA can cause large fluctuations in TB, which will appear in the data.

Table 2 summarizes the quantitative results from the direct comparison, single difference, and double difference. The yearly max/min difference is shown as the metric to compare the direct calibration and single difference, and the calibration difference is shown to contrast the direct comparison and double difference for inter-calibration. These values are given for the globe, NH, and SH using AMSR-E 23.8V GHz and TMI 21.3V GHz channels.

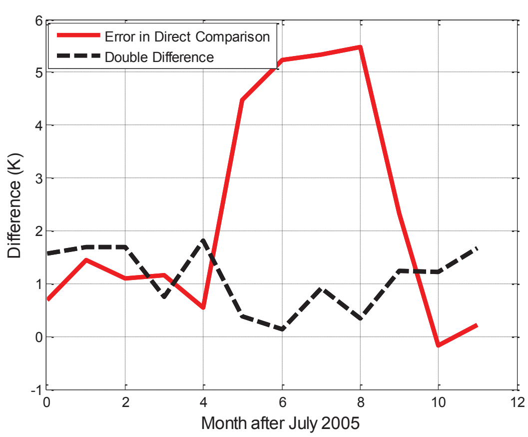

Figure 5: Comparison of double difference and the error in performing a direct comparison by month.

	Yearly max/min Difference (K)		
AMSR-E	*Globe*	*NH*	*SH*
Direct Calibration	1.57	8.67	1.93
Single Difference	0.94	1.29	1.24
	Calibration Difference (K)		
AMSR-E – TMI	*Globe*	*NH*	*SH*
Direct Comparison	3.21	5.01	2.51
Double Difference	1.26	1.11	1.64

Table 2: Summary of quantitative results for the three forms of calibration for the globe, NH, and SH.

4. SUMMARY

The method of the double difference for GPM inter-calibration was presented along with an analysis of the robustness of the algorithm. The double difference was shown to be more accurate as an inter-calibration method compared to direct comparison due to the inclusion of simulated radiometer TBs. As shown with the single difference, these simulated TBs can remove geophysical variability due to seasonal changes, as well as any EIA variations within the data. The single difference does not perform as well when the cold cal algorithm is not able to find the global minimum TB, as in the case when latitudes are restricted.

5. REFERENCES

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