A CONSENSUS CALIBRATION BASED ON TMI AND WINDSAT

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ABSTRACT

The Global Precipitation Measurment (GPM) mission requires a high degree of consistency among the microwave radiometers in the constellation which, in turn, demands a standard against which all the sensors can be compared. Ultimately this standard will be the GPM Microwave Imager, but for the present the TRMM Microwave Imager (TMI) fills this need. Since its calibration leaves much to be desired, a refinement using Windsat has been developed. This article defines the Consensus Calibration 1.1 which is applied to the TMI. In turn the TMI serves as a transfer standard to other satellite radiometers.

Index Terms— Microwave radiometry, calibration, precipitation

1. INTRODUCTION

The Global Precipitation Measurment (GPM) mission is based on using a constellation of spaceborne microwave radiometers to achieve the needed sampling. To avoid artifacts in the composite precipitation fields, the radiometers must be calibrated in a consistent way. We have developed methods to compare brightness temperatures of instruments with somewhat different viewing parameters (frequency and incidence angle). It appears that the relative calibration can be done to about 0.1K (perhaps slightly worse near the 22 GHz water vapor line). However, in spite of the lack of adequate standards, the absolute calibration should also be as accurate as possible. To the extent the calibration of different sensors is independent, appropriately weighted averages would be expected to have a better calibration than any single instrument. We will term a calibration based on more than one microwave radiometer a "Consensus Calibration". Here we examine a consensus based on the TRMM Microwave Imager (TMI) and Windsat. The TMI data used are Version 7 which includes the recently derived solar bias correction[1]. Since TMI is in a low inclination orbit and Windsat is in a near polar orbit, there are many orbital intersections over a wide range of latitudes to facilitate this comparison.

TMI is on the Tropical Rainfall Measurement Mission (TRMM) satellite, launched in 1997. It measures radiance at 5 frequencies (10.65, 19.35, 21.3, 37 and 85.5 GHz) in both H and V polarization (except for 21.3 which is V only). It scans conically with a nearly constant earth incidence angle of 53.4°. TRMM is in a non-sun-synchronous orbit with a 35° inclination

Windsat is a 5 frequency (6.8, 10.65, 18.7, 23.8 and 37 GHz) radiometer launched into a near-polar, sun-synchronous orbit in 2003 on the Coriolis satellite. The radiometer has at least H and V polarizations at all frequencies. The additional polarizations needed for its mission, measurement of the wind speed and direction at the ocean surface, are not used here. It scans conically and takes data in both the forward and aft directions; only the forward views are considered here. Incidence angles vary by frequency from around 50° to 55° in addition to the usual variations due to spacecraft attitude, orbital eccentricity and the ellipsoidal shape of the Earth. The data are only usable for a portion of each frequencies swath. We only use the portions of the swaths common to all frequencies.

2. COMPARISON METHODS

Here we will use the Windsat observations to generate synthetic observations for the 7 low frequency channels of TMI for comparison. Four approaches to comparing sensors over the ocean are being used. The first three are based on nearly simultaneous observations of the two sensors averaged over 1 degree boxes with stringent brightness temperature variance and time difference limits. The fourth approach uses relatively stable on-Earth targets as references for sensor comparisons. The combination of multiple approaches is termed "Unified Calibration" as distinct from the "Consensus Calibration" above. In all cases the results are examined in a double difference mode to minimize the impact of model assumptions. Each approach is used to compute what differences are to be expected due to the differences between the viewing parameters of each pair of channels on the two sensors. This difference is subtracted from observed differences between the same pair of channels to get the calibration difference between the two channels on the two different sensors., thus, a "double difference".

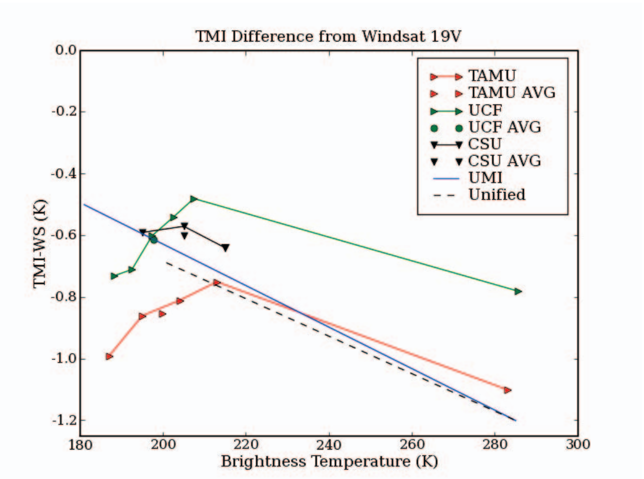

Figure 1
Warm and cold end calibration differences between TMI and Windsat using the methods discussed above. The TAMU, UCF and CSU methods permitted partitioning the results as a function of the TMI brightness temperature. Both the partitioned and averaged brightness temperature differences are shown

The University of Central Florida algorithm uses the atmospheric profile and surface parameters specified by Global Data Assimilation System (GDAS) analyses to compute both the source and target sensor brightness temperatures for each matched 1 degree box.

The Colorado State University (CSU) algorithm [2] adjusts cloud liquid water, sea surface wind and precipitable water to match the observed brightness temperatures and incidence angles of the source sensor. The temperature and water vapor profiles are loosely constrained with covariance matrices and the sea surface temperature is externally supplied. With the so-determined geophysical parameters the brightness temperatures of the target sensor are computed for the appropriate incidence angles.

The Texas A&M University (TAMU) algorithm is similar to the CSU algorithm except that it also adjusts the sea surface temperature along with the other geophysical parameters and uses a fixed lapse rate and relative humidity profile. The precipitable water is varied by adjusting the atmospheric temperature.

The University of Michigan (UMI) algorithm [3] collects histograms of brightness temperatures for the entire test year over the portion of the earth common to the two sensors. The histograms are analyzed to determine a minimum brightness temperature for each channel. Simulation calculations are then used to determine the differences expected due to the differing frequencies and incidence angles.

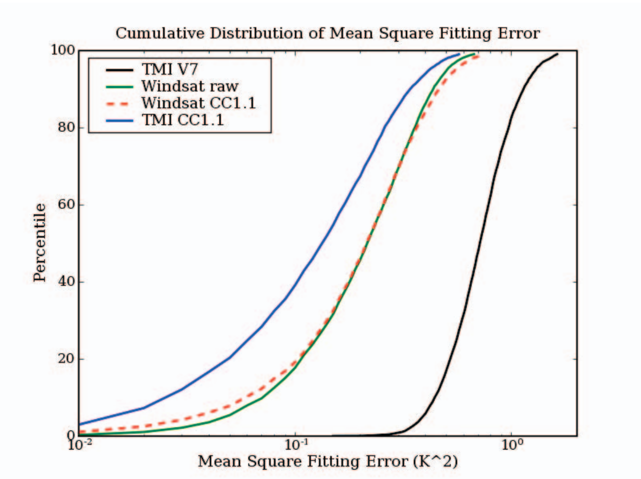

Figure 2
Distribution of the penalty functions (mean square TB residuals) from fitting the 7 low frequency channels of TMI and the corresponding channels of Windsat using the TAMU algorithm

At the warm end, the Amazon rain forest is used as a transfer standard. Several groups use the UMI model [4] for comparison of different sensors. Geophysical parameters for the Amazon observations (canopy temperature andalbedo, precipitable water) are retrieved from the reference sensor and used in a simplified forward radiative transfer model to predict the brightness temperatures of the target sensor.

Since the UMI version is the most mature implementation, it alone is used at the warm end. The TAMU algorithm treats the surface as a mixture of a high emissivity grey body and open water. At each frequency with two polarizations, the algorithm solves for the apparent fraction of open water and the surface temperature. These parameters are interpolated to the frequencies of the other sensor and used for a forward calculation of the synthetic observations. This is much simpler than the UMI algorithm and is only shown as a sanity check. Note that agrees with the UMI result to less than 0.1K in Figure 1.

3. UNIFIED CALIBRATION

The methods above were used to predict the differences between what Windsat predicted the TMI brightness temperatures should be and the actual TMI observations; a typical case, 19 GHz V polarization, is shown in Figure 1. These 3 methods were sorted in two ways. First all the cold end data were averaged for a single offset at a single brightness temperature, the AVG values in Figure 1. Each team also partitioned their results according to TMI

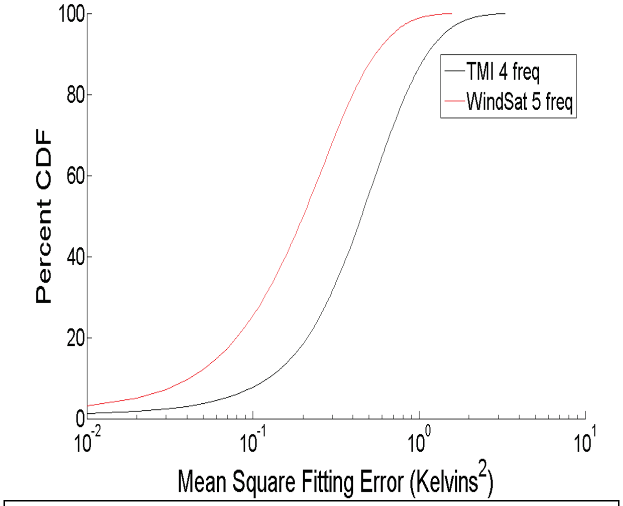

Figure 3
The warm end (Amazon Basin) analog to Figure 2 using the UMI model. The Windsat result is on the left and TMI on the right.

brightness temperature. Potential values of the Unified Calibration were also derived based on the lowest TB bins. After transforming the results to a common set of Brightness temperatures, Unified Calibrations were derived based on both approaches with uniform weights for the TAMU, UCF and CSU cold end methods. For the 21V channel, the statistical uncertainty in the average was significantly less using the lowest bin values, while for all other channels the statistical uncertainty was either less using all the data or too small to matter. Most likely the differences result from sensitivity to the vertical distribution of water vapor. The statistical uncertainties in the Unified Calibrations were of the order 0.1K for all channels with the 21V channel being at the high end of this range. The Unified Calibration is shown as the dashed line in Figure 1. It is expressed as a linear transformation based on the points given in Table 1. This transformation describes the adjustments that would be required to make TMI consistent with Windsat. Note that most values are negative indicating that TMI radiances are low relative to Windsat.

4. CONSENSUS CALIBRATION

The next step is to determine what the relative weights of TMI and Windsat should be in a Consensus Calibration. The Windsat mission, to investigate the use of microwave radiometers to measure both wind speed and direction over the ocean, is extremely demanding on the quality of the calibration and the sensor had commensurate care applied toits calibration. On the other hand, TMI had technical problems that compromised the calibration and the corrections[1] are inherently imperfect Thus one would expect the calibration of Windsat to be better and a consensus calibration should be heavily weighted towards Windsat. However, this logic is impossible to quantify.

Table 1
DIFFERENCES BETWEEN TMI AND WINDSAT

Channel	Δ TB	@ TB	Δ TB	@ TB
10V	0.31K	163K	-0.76K	281K
10H	-1.66	85	-0.92	280
19V	-0.61	188	-1.20	285
19H	-3.20	109	-1.43	284
21V	-1.89	200	-3.37	284
37V	-3.24	206	-3.17	281
37H	-2.41	135	-3.16	281

The CSU and TAMU methods, since they adjust fewer geophysical than the number of brightness temperatures, yield a measure of self consistency, albeit with respect to the radiative transfer model assumptions. The TAMU method was used to estimate the relative quality at the cold end. In Figure 2, we show the statistics of the penalty function for TMI and Windsat when the 7 channels common to both are fitted. Since the quantity shown is a variance, the weights should be inversely proportional to the values. Over the bulk of the range, the TMI variances are a little more than 3 times the Windsat variances. The UMI warm end model was similarly used to estimate the quality at the warm end. Here the TMI values run a little less than 3 times the Windsat values. These suggest that the weight of Windsat should be about 3 times that of TMI; it would be difficult, and perhaps unwise, to define the relative weights finer based on this level of information. Thus we define Consensus Calibration 1.1 to have a weight of 75% Windsat and 25% TMI. The brightness temperatures of TMI when transformed to this consensus are much more consistent with the model than the uncorrected data while the consistency of Windsat is virtually unchanged as can be seen in Figure 2.

Table II
Consensus Calibration 1.1 Adjustments to TMI

Channel	Δ TB	@ TB	Δ TB	@ TB
10V	0.23	163	-0.57	281
10H	-1.25	85	-0.69	280
19V	-0.46	188	-0.90	285
19H	-2.40	109	-1.07	284
21V	-1.42	200	-2.53	284
37V	-2.43	206	-2.38	281
37H	-1.81	135	-2.37	281

Table III Consensus Calibration 1.1 Adjustments to Windsat				
Channel	Δ TB	@ TB	Δ TB	@ TB
10V	-0.08K	163K	0.19	282K
10H	0.41	87	0.23	281
18V	0.15	189	0.30	286
18H	0.80	112	0.36	285
23V	0.47	202	0.84	287
37V	0.81	209	0.79	284
37H	0.60	137	0.79	284

5. FUTURE WORK

Efforts are underway to develop an improved Consensus Calibration. The UMI cold end algorithm has been refined and will be included in the next Unified Calibration. An independent warm end calibration algorithm has been developed at UCF and will also be included. Each algorithm developer is generating an estimate of the uncertainty in his algorithm which will be used for determining the weight of each calibration estimate in the Unified Calibration. We are also seeking alternative ways of estimating the TMI and Windsat weights in the Consensus Calibration. None of these is expected to change the calibration adjustments very much; the point is to have an approach that is as rigorous and defensible as possible.

6. REFERENCES

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