GEOPHYSICAL RESEARCH LETTERS, VOL. 26, NO. 15, PAGES 2379-2382, AUGUST 1, 1999

First Results of the TRMM Microwave Imager (TMI) Monthly Oceanic Rain Rate: Comparison with SSM/I

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Abstract. We evaluated the performance of the Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI) at-launch algorithm for monthly oceanic rain rate using six months (January – June 1998) of TMI data. Comparison with oceanic monthly rain rates derived from the Special Sensor Microwave Imager (SSM/I) data shows statistically significant differences. The TMI rain rates are lower than the SSM/I rain rates by about 10% overall, except for rain rates lower than 1.4 mm/day. The low TMI bias may be due to an overestimate of the columnar water vapor as indicated by the estimated rain layer thickness. The superior sampling by the TMI improves the algorithm statistics at the low rain rates. The averaged monthly rain rates over the latitudes between 40°S and 40°N are 2.78 and 3.17 mm/day, respectively for TMI and SSM/I, with RMS difference of 1.35 mm/day and correlation coefficient of 0.94.

Introduction

Precipitation is one of the most crucial and least known climate parameters in the global water and energy cycle. The Tropical Rainfall Measuring Mission (TRMM) is a joint effort between the National Aeronautics and Space Administration (NASA) of US and National Space Development Agency (NASDA) of Japan to study tropical and subtropical rain systems (*Simpson*, 1988). Planned for a three-year mission, the rain monitoring sensors on board the TRMM satellite includes the first space-borne precipitation radar (PR), a TRMM Microwave Imager (TMI), and a Visible- Infrared Scanner (VIRS). Detail descriptions of the TRMM sensors, algorithms, and data appear in the following web page: URL: http://trmm.gsfc.nasa.gov/.

Global rainfall estimates from different techniques vary widely. An objective of the TRMM is to obtain a minimum of three years of monthly rainfall in the tropics over 5° latitude by 5° longitude boxes with an accuracy of 1 mm/day or 10% in heavy rain. This stringent requirement is mandated by the lack of reliable monthly rainfall data to validate global atmospheric models on seasonal to inter-annual time scales. Since the TMI and VIRS have their heritage from Special Sensor Microwave Imager (SSM/I) and Advanced Very High Resolution Radiometer (AVHRR), respectively, the rain data collected by TRMM can be used to calibrate existing techniques for rainfall estimation.

At an altitude of 350 km and an inclination of 35°, the circular TRMM orbit has a period of about 92 minutes and precesses with an approximate repeat cycle of forty days. This slow precession allows sampling through the diurnal cycle over the course of a month and hence TRMM data will provide insight into the diurnal biases associated with sampling by the polar operational satellites such as the NOAA or DMSP series.

In this report, we examined the performance of the at-launch algorithm of the TMI monthly oceanic rain rates (or algorithm 3A11 as referenced by the TRMM Science Data and Information System which processes the standard TRMM products). This algorithm is based on the technique developed by *Wilheit et al.* (1991) and has been applied to over eleven years of Special Sensor Microwave Imager (SSM/I) data (*Chang and Chiu*, 1999). As a standard TRMM product, data quality of this product must be assessed to allow usage by other researchers.

In section 2 differences between the SSM/I and TMI sensor, platform, algorithm and data are discussed. Comparison results are presented in Section 3. Discussions are contained in Section 4.

SSM/I and TMI Sensor and Data Characteristics

The SSM/I is a seven channel four-frequency (19.35, 22.235, 37 and 85.5 GHz) microwave radiometer. Detailed description of the SSM/I is given by *Hollinger et al.* (1990). Currently, SSM/I on board of the DMSP F11, F13 and F14 satellites are collecting data. Characteristics of the TRMM sensors are described by *Kummerow et al.* (1998). The TMI has an additional 10.7 GHz channel, which provides a more linear response to high rainfall rates. The water vapor channel of TMI is centered at 21.3 GHz, or about 1 GHz away from that of SSM/I 22.235 GHz channel. This makes the response of the TMI water vapor channel less susceptible to saturation due to water vapor.

The DMSP satellites are nominally in a sun-synchronous orbit. Observations are restricted to two narrow intervals of local solar time. At the equator, these intervals extend from 0520 to 0615 local time (LT) (0810 to 0905 LT) for the ascending portion of the orbit and from 1720 to 1815 LT (2005 to 2105 LT) for the descending portion of the orbit for the DMSP F13 (F14) satellite, respectively. As no orbital adjustments are anticipated for the DMSP satellites, these equatorial crossing times tend to drift slowly in time.

The TMI covers the global tropics between 37.5° N and 37.5° S. Over the course of a month, the TRMM satellite makes the equivalent of about 30 full visits over most of the 5° latitude by 5° longitude gridded area. This temporal coverage is comparable to that of the SSM/I. However, the TRMM

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Paper number 1998GL900452.

sampling is not uniform over the 24 hour period during the course of a month, and hence the sampling may still introduce some diurnal bias in the monthly rainfall estimates.

The *Wilheit et al.* (1991) technique uses a combination channel to reduce the effect of water vapor variability. The rain rate distribution is assumed to be mixed-lognormal. The parameters of the mixed-lognormal rain rate distribution are matched iteratively to the observed histogram of brightness temperature (T_B) of the combination channel via a rain rate-brightness temperature (R-T_B) relation. The rain layer thickness (FL) is determined using information from the upper 99 percentile of the 19 and 22.235 GHz T_B histogram. In cases where there is no numerical convergence due to limited sample size, arithmetic averages of the rain rates are computed as the monthly average. The combination channel for SSM/I is twice the vertically polarized 19 GHz minus the 22.235 GHz (*Wilheit et al.*, 1991). For the TMI algorithm, the combination channel is twice the 19 GHz minus the 21.3 GHz. The R-T_B relation for TMI is slightly adjusted for the shift in central frequency.

Six months (January -June1998) of oceanic rainfall data are compared. Monthly TMI rain rates are computed from TMI brightness temperature data. The TRMM standard products are available through the Distributed Active Archive Center of the Goddard Space Flight Center (URL: http://lake.nascom.nasa.gov/data/TRMM/). The SSM/I F13 and F14 monthly means are produced by the Global Precipitation Climatology Program (GPCP) Polar Satellite Precipitation Data Center, and are available through the following Web site (URL: http://ltpwww.gsfc.nasa.gov /PSPDC/SSMI.rain.rate.html.)

Comparisons of the Monthly Rainfall

For each 5° x 5° box, three estimates are available, namely TMI, and F13 and F14 SSM/I, respectively. We examined the difference between F13, F14, and TMI. Figure 1 shows the histogram of the difference between F13 and F14, TMI and F13, and TMI and F14 estimates for all six months. There is zero bias between the F13 and F14 estimates and the difference histogram is centered at and symmetric about zero. The histogram of TMI and F13 or F14 difference is skewed, indicating that the TMI rain rate is lower than the F13 or F14 rain rates.

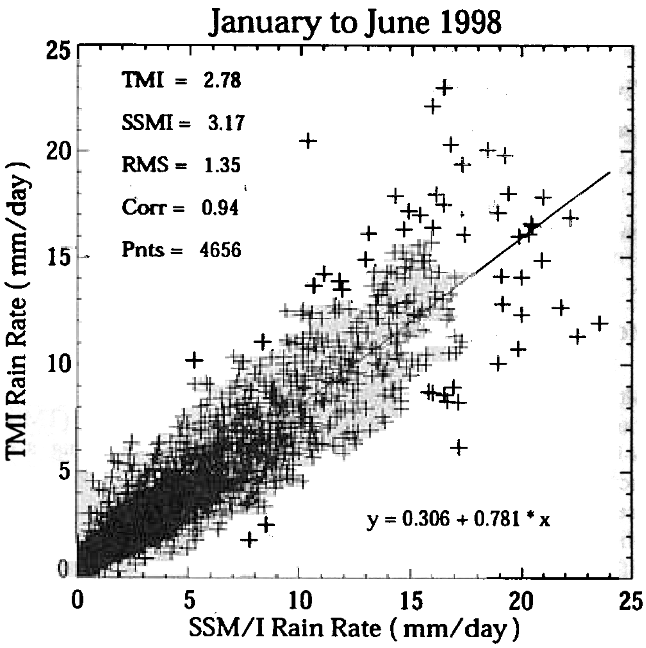

Figure 2. Scatter diagram of six months of SSM/I and TMI rain rates (January – June 1998). The units are in mm/day, except for correlation (corr) and the total number of grid boxes (Pnts) which are non-dimensional. The solid line shows the linear regression line.

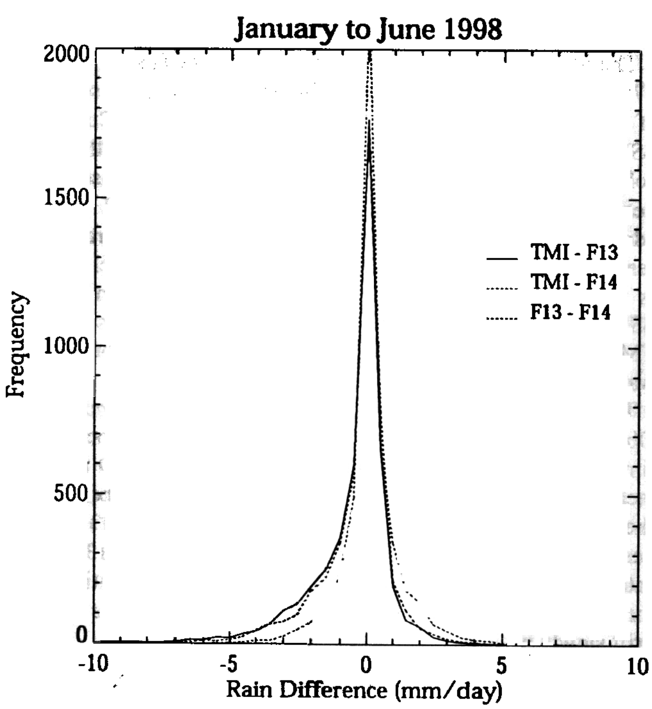

Figure 1. Histogram of the difference between monthly rain rates derived from F13 and F14, between TMI and F13, and between TMI and F14.

Chang and Chiu (1999) argued that if the F13 and F14 estimates are independent, then an average of the F13 and F14 SSM/I rain rate yields a better estimate in which the non-systematic error is reduced according to the square root of the sample numbers. We compute an SSM/I mean as the average of the monthly means of the F13 and F14 estimates.

Figure 2 shows the scattergram of TMI vs. SSM/I rain rates for January – June 1998. The means of the TMI and SSM/I rain rates over the six months are 2.78 and 3.17 mm/day, respectively, i.e., the TMI is lower by about 10%. The RMS difference is 1.35 mm/day, with correlation coefficient of 0.94. Regression analysis shows a slope of 0.78 and an intercept of 0.31. The regression line crosses the 45degree line at about 1.4 mm/day. Below this rain rate, the TMI estimates are higher than the SSM/I, whereas the SSM/I estimates are higher than the TMI estimates above this threshold.

Figure 3 shows the average (January –June 1998) rain rate for the TMI (upper panel) and SSM/I (middle panel). We tested the differences between the TMI and SSM/I means using a paired t-test (*Bulmer*, 1979; *Chang et al.*, 1995). At each 5° x 5° latitude/longitude grid box, the following t-statistic is compute

$$t = (\langle x \rangle - \mu_0) / (\sigma_x / n^{1/2}) \qquad (1)$$

where x is the TMI minus the SSM/I mean, x = R(TMI) – R(SSM/I), $\langle x \rangle = 1/n \, \Sigma \, x$ is the ensemble average of x, μ_0 the population mean, σ_x the standard deviation of x, and n=6 is the number of samples, corresponding to January – June 1998 monthly data. For n-1 or 5 degrees of freedom, the null

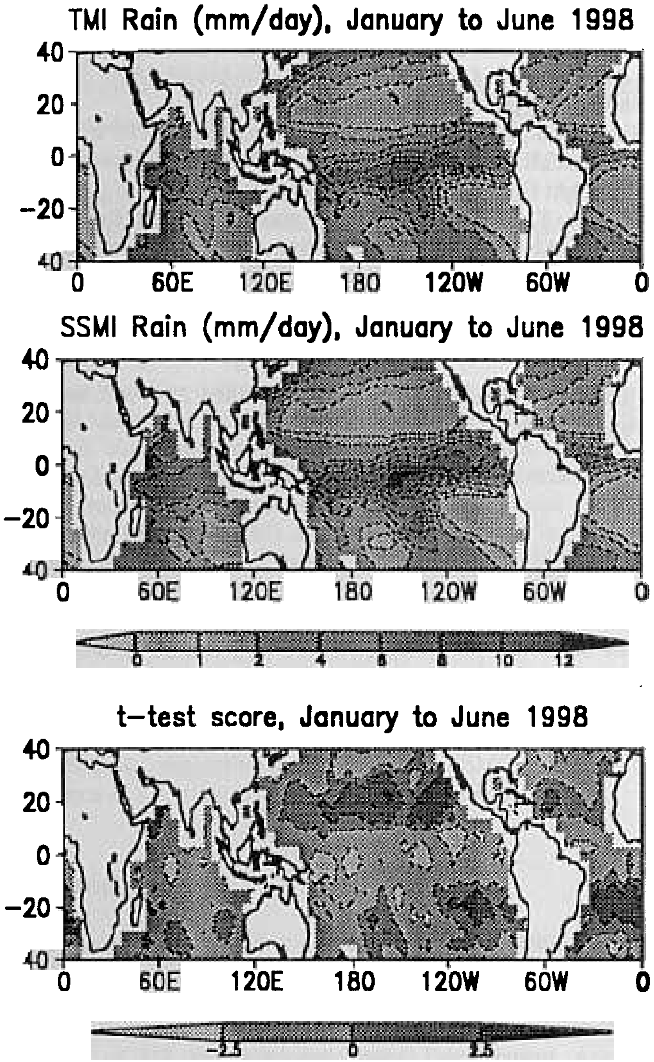

Figure 3. Distribution of the average monthly (Jan – June 1998) rainfall derived from the average of F-13 and F-14 SSM/I (upper), TMI (middle), and paired t-statistics (lower panel). The units are in mm/day for SSM/I and TMI rain rates.

hypothesis that $\mu_0=0$ is rejected at the 5% confidence level when |t| exceeds 2.57 for a two tail test. The lower panel of Fig. 3 shows the t statistics distribution. In total, there are 1152 (16x72) 5°x5° latitude/longitude boxes, of which 376 are over land and hence not counted, 630 with $|t| < 2.57$ and 146 with $|t| > 2.57$. The high |t| value boxes represent 18.8% of the total oceanic grid boxes, representing a statistically significant difference between the TMI and SSM/I estimates. The regions with large positive t values ($t > 2.57$) are located in the oceanic dry regions whereas the large negative t values ($t<2.57$) appear in the Inter-tropical Convergence Zone and the South Pacific Convergence Zone. This is consistent with results of the regression analysis in Figure 2.

Discussions

We compared the first six months of TMI monthly rainfall processed by the at-launch algorithm with that derived from SSM/Is abroad the DMSP F13 and F14 satellites. There is no significant difference between the F13 and F14 SSM/I rain rates. Since the SSM/I rain rates are oceanic products of the Global Precipitation Climatology Project (GPCP), their continued production and monitoring will ensure a high quality oceanic rainfall product that is of sufficient duration for GCM calibration and seasonal and inter-annual climate studies.

Statistically significant differences exist between TMI and SSM/I monthly rain rates. The TMI estimates are lower than the SSM/I rain rates by about 10% overall, but are higher for rain rates < 1.4 mm/day.

Post launch calibration showed a bias of about 10^0K at the cosmic background across all TMI channels (*Shiue*, 1998). The bias in the combination channel (about 3^0K at a T_B of 200^0K) is not expected to change the parameters of the rain rate distribution substantially because in the retrieval process, only the first three moments of the brightness temperature histogram are fitted. Calibration biases will shift the histograms but will not change their shapes.

This calibration bias, however, could introduce a substantial bias in the rain layer thickness (FL). The FL is a proxy index of the columnar water content. In separate studies using one year of TRMM data, we found that the TMI-derived FL is higher than the SSM/I-derived FL by about 200m and the TRMM Precipitation Radar-derived melting height by about 500m. The FL is tightly coupled to the rain rate (*Wilheit et al.*, 1991, equation (4)). If the FL is over-estimated by 10%, about a 10% lower rain rate results.

Cruz Pol and Ruf (1996) compared radiosonde-derived radiometric data with measurements for frequencies around the water vapor absorption band. They showed that the water vapor emission spectra computed from the current set of parameters might have been under-estimated by 3% to 7%. The new set of parameters they derived would increase the zero rain point on the 19 and 21.3 GHz T_B diagram by about 1 K.

The superior sampling by the TMI is clearly demonstrated for retrievals at low rain rates. The number of TMI pixels over a 5^0 by 5^0 grid box is larger than that of the SSM/I by over an order of magnitude. Over the oceanic dry zones, the number of rainy pixels within a 5-degree grid cell sampled by the SSM/I is small, and numerical convergence is not always achieved. In these cases, the algorithm resorts to arithmetic averaging which may introduce a low bias.

We examined the number of samples as a function of time-of-the-day for each of grid box. Subtle difference in the rain rates can be attributed to the sampling differences between TRMM and DMSP satellites. For example, for an early morning peak in oceanic rain rate (*Chang et al.*, 1995), the TMI sampling for March 1998 at the high northern latitudes (35°N) would under-sample the morning peak and over-sample the late afternoon minimum, thus giving a somewhat lower monthly mean at these latitudes. Monthly SSM/I rainfall is based on averages of both AM and PM estimates, hence removing the bias due to the first harmonic of the diurnal cycle. Higher harmonics, however, could still introduce a bias in the monthly means.

From our analyses, we found that the TMI rain rate is lower than the SSM/I estimates. The difference may be attributed to a calibration bias in the TMI and a minor correction in the water vapor emission spectra. Based on these finding, we are modifying the at-launch algorithm that will be used for the next reprocessing of TMI monthly rainfall scheduled for the fall of 1999.

Acknowledgments. This work is supported by NASA Office of Earth Sciences through grant TRMM NRA (96-MTPE-06). The TMI brightness temperature data are supplied by the TRMM Science Data and Information System.

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(Received February 15, 1999; revised May 27, 1999; accepted June 1, 1999.)