P1.2 TRMM AND THAILAND DAILY GAUGE RAINFALL COMPARISON

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1. INTRODUCTION

Accurate estimation of rainfall is crucial for crop yield assessment, water resource management and flood and drought monitoring. Excess rainfall causes severe flooding, property and lives loss. Extended absence of rainfall lead to droughts, which can devastate crop yields and limits human consumption. Thailand is heavily dependent on rain-fed agriculture, hence excess or insufficient rainfall can be devastating to the national economy and the livelihood of its people. A better understanding of the spatial and temporal rainfall distributions is therefore essential for the Thai economy.

Rain gauge measurements are usually limited by their spatial coverage. A network of weather radars provides good spatial and temporal coverage. However, the problem of inter-radar calibration and blockage by mountains still limit its capability. Remote sensing techniques using spaceborne sensors provide an excellent complement to continuous monitoring of rain event both spatially and temporally. The launch of the Tropical Rainfall Measuring Mission (TRMM) satellite in November 1997 by National Aeronautics and Space Administration (NASA) of US and the Japanese Aerospace Exploration Agency (JAXA) provided more than seven years of quality rainfall data for tropical rainfall study. The recent decision to extend TRMM operations to 2009 further increases its potential value for application use. To improve the TRMM data quality, TRMM products are constantly reprocessed, as new information acquired by TRMM lead to improved algorithms. Recently, the TRMM reprocessing was completed using the Version 6 (V6) algorithms. It is necessary to quantify the biases of the TRMM products relative to gauge measurements that have been used historically to calibrate hydrologic and agricultural models. A comparison of Thailand rain gauges with the global precipitation climatology centre (GPCC) allows an assessment of the quality of the gauge data. Comparison with TRMM products enables an evaluation of the applicability of satellite rain estimates in Thailand for agricultural and hydrological applications. The validation of TRMM rainfall products would aid in the refinement of rainfall algorithms for TRMM and the planned NASA Precipitation Measurement Mission (PMM).

There are a number of efforts to compare and validate TRMM rainfall products with other rainfall measurements (Chiu et al., 2005a,b). However, these studies are usually limited to comparisons at the monthly scale. For hydrological or agricultural applications, shorter periods, such as daily, five day (pentad) or ten day (decad) rain rates are more appropriate. More recently, comparison of operational rain products at the daily scale have been carried out for the continental US, Europe and Australia (Ebert, 2002). The comparison over Asia, and in Thailand, in particular, is lacking. In this study, we compare Thailand daily rain gauge dataset with the daily TRMM Level 3 rainfall products and monthly gauge analyses produced by the GPCC and TRMM.

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2. DATA SETS

Table 1 shows the data sets and their characteristics used in this study.

2.1 *Thailand Rain Gauge dataset (TG)*

Thailand Rain Gauge data are obtained from the Thai Meteorological Department (TMD). Ten years (1993-2002) of daily rain rates are collected from more than a hundred rain gauge stations over Thailand. Figure 1 shows the location of the gauge stations. The dataset is separated into five regions: north, central, north-east, east and south. Figure 2 shows the boundary of five regions over Thailand. The data are firstly binned into 1°x1° boxes. The box average rain rate is computed by weighting the gauge values at each gauge by its inverse square distance from the grid center. There are approximately 50 boxes with at least 1-2 gauges within each 1°x1° box.

Data Set Name	Spatial resolution	Temporal resolution	Duration
Thailand gauge (TG)	Binned to 1x1 degree	Daily (0-23Z)	Jan 1993- Dec 2002
GPCC	1 x 1 degree	Monthly	1986-present
TRMM 3B43 V5	1 x 1 degree	Monthly	Jan 1998 – Mar 2004
TRMM 3B42 V5	1 x 1 degree	Daily (0-23Z)	Jan 1998 – Mar 2004
TRMM 3B43 V6	0.25 x 0.25 degree	Monthly	Jan 1998- present
TRMM 3B42 V6	0.25 x0.25 degree	3 Hourly	Dec 31, 1997-present

Table 1. Characteristics of the data sets used in this study

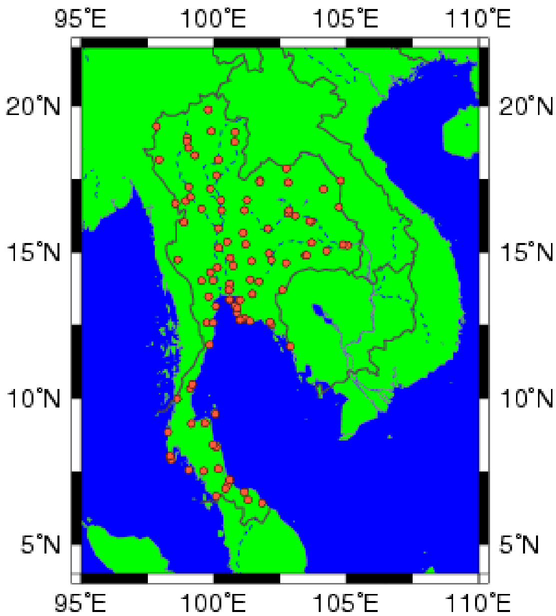

Figure 1. The distribution of Thailand rain gauges

Figure 2. The boundary of Thailand regions

2.2 *Global Precipitation Climatology Centre (GPCC)*

As part of the Global Precipitation Climatology Project (GPCP), the GPCC is responsible for producing precipitation estimates over land. GPCC collected global rain gauge data and produces a near real-time (shortly after the month ends) monthly monitoring product based on a subset of about 7,000 stations. The precipitation data are distributed as monthly (CLIMAT) reports and synoptic (SYNOP) reports via the Global Telecommunication System of the World Weather Watch (GTS) of the World Meteorological Organization (WMO). This dataset was produced at the GPCC for the Global Precipitation Climatology Project (GPCP) (Rudolf et al., 1994). The product is directly accessible via the GPCC website [http://gpcc.dwd.de].

2.3 *TRMM 3B42 and 3B43 Version 5 (V5) Algorithm*

The major rain measuring sensors for the TRMM are Precipitation Radar (PR), TRMM Microwave Imager (TMI) and Visible and Infrared Scanner (VIRS). A TRMM Combined Instrument Algorithm (TCA, 2B31) is also developed that make use of the attenuation measured by TMI as a constraint to PR rain profiles at the PR swath. Kummerow et al. (2000) provided a good description of the TRMM project and instrument performance. A list of TRMM standard, value-added and ancillary products are available from the GDAAC Precipitation Data and Information Services Center (PDISC) website [http://daac.gsfc.nasa.gov/precipitation/data_access.shtml] and are described in Chiu et al., (2005a). Comparisons the TRMM V5 and V6 algorithms have been performed (Chiu et al., 2005b).

The TRMM V5 3B42 is a TRMM calibrated IR rain product. Coincident TCA and VIRS (TSDIS referenced 1B01) data are analyzed to establish transfer coefficients between TCA and VIRS. This relation is used to calibrate IR estimates from geosynchronous satellite infrared data to form the V5 3B42 product. Global estimates are made by adjusting the Geosynchronous satellite Precipitation Index (GPI) to the TRMM estimates. The V5 3B42 algorithm provides daily precipitation and root mean square (RMS) error estimates at 1°x1° latitude/longitude grids in the TRMM domain 40°N to 40S° (Huffman et al., 2001).

The V5 3B43 product is produced by merging the monthly accumulation of daily V5 3B42 with the monthly accumulated Climate Assessment and Monitoring System (CAMS) or GPCC rain gauge analysis (3A45) (Huffman et al., 1995). The monthly accumulation of 3B42 and gauge analyses are weighted by the inverse of their respective random error fields (Huffman et al., 1997). The V5 3B43 algorithm provides 1°x1° gridded monthly precipitation product.

2.4 *TRMM 3B42 and 3B43 Version 6 (V6) Algorithm*

The V6 3B42 is a 3 hourly 0.25 degree product based on multi-satellite precipitation analysis (MPA, Huffman et al., 2004). First, all available microwave (from TRMM, Special Sensor Microwave Imager (SSM/I), Advanced Microwave Scanning Radiometer (AMSR) and Advanced Microwave sounding Unit (AMSU)) and calibrated IR estimates are put into the appropriate space/time bins. These instantaneous estimates are summed over a calendar month to create a monthly multi-satellite (MS) product. The MS and gauge analysis (GPCC or CAMS) are merged optimally as done in Huffman et al. (1997) to create a post-real-time satellite-gauge (SG) monthly 0.25° product, which is the TRMM product V6 3B43. The final V6 3B42 is then scaled as the ratio of monthly MS to SG (the scale factor being limited to a range [0.2,2]). The gauge analyses employed are presented on a 2.5° grid or 1° grid, so that the information at the 0.25° 3B42 and 3B43 data are attributed to satellite inputs.

3. RESULTS

To compare these rain estimates, the following statistical measures are used- bias, root mean square difference (RMSD) and mean absolute difference (MAD). These are defined as follows:

$$\text{Bias} = \frac{1}{n}\sum_i (x_i - TG_i)$$

$$\text{RMSD} = \sqrt{\frac{1}{n}\sum_i (x_i - TG_i)^2}$$

$$\text{MAD} = \frac{1}{n}\sum_i |x_i - TG_i|$$

where n is the total number of samples, i = 1, …, n and x is the algorithm rain rate and TG is the Thailand gauge analyses for the grid box.

3.1 *Thailand Climatology*

Figure 3 shows the seasonal rainfall for the different regions of Thailand. Climatologically, Thailand has a dry season (December to April) and a rain season (May to September). The south and east show the highest rainfall. Rain in the south show a minimum in February and a maximum in November. There are two rainfall peaks during the rain season. For the onset, there seem to show a northwest progression -the early rainfall peaks first in the east, northeast, central, and then north regions. The end of the rain season occurs from north to south, with the secondary peak occurring in August in north and northeast regions and in September in central and east regions, consistent with the movement of the Intertropical Convergence Zone (ITCZ) rain bands.

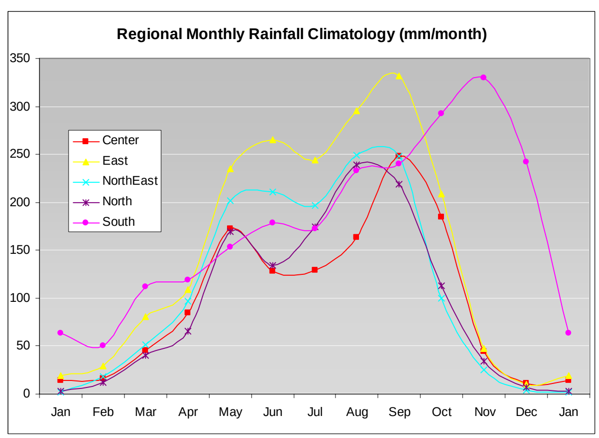

Figure 3. Thailand seasonal rainfall climatology for different regions

3.2 *Monthly Comparison*

We extract data between latitude 6°N - 20°N and longitude 98°E - 105°E which covers the Thailand region from all data sets. The comparisons are carried out at 1°x1° latitude/longitude boxes for the periods of overlap. Statistical analyses are performed based on monthly and daily data, respectively. The daily

TG, V5 and V6 3B42 data are averaged to 1 degree and monthly for monthly comparison.

Figure 4 shows the seasonal cycle of Thailand rainfall for all rain estimates. TG and GPCC are computed from 10-year data (1993-2002) and TRMM 3B42 and 3B43 from 5-year data (1998-2002). All estimates show double peaks in May and August, respectively, during the rain season. The GPCC and V6 3B43 show low biases compared to the other products. The V5 3B42 is the highest and overestimates the gauge measurement throughout most of the year (except in February). During the rain season, TG estimates are close to GPCC estimates. Table 2 summarizes seasonal average TG rain rates and biases from all data sets.

The 10-year averages of TG and GPCC are 138.38 and 136.99 mm/month respectively. From the seasonal time series of the TG and GPCC (figure not shown), the large seasonal amplitude in the early years 1994-1997 compared to the later years 1998-2000 are noted. However, the time series of the non-seasonal TG and GPCC track each other very well, with a correlation of 0.96.

Figures 5 show the time series of 3B42 and 3B43 with TG for V5 (Figure 5a) and V6 algorithms (Figure 5b). There are good agreements between these products. The correlation between TG and GPCC, V5 3B42, V5 3B43, V6 3B42 and V6 3B43 are 0.99, 0.96, 0.97, 0.99 and 0.99 respectively for the seasonal data. For the V5 algorithms, there is good correspondence between 3B43 and TG except for January 2002. V5 3B42 tends to overestimate, especially in the rainy months. For the V6 algorithms, the discrepancy between TG and 3B43 in January 2002 disappeared, probably due to the use of better quality controlled GPCC data for the merging. Such a discrepancy for individual months is also noted in the comparison of TRMM and water division data over New Mexico (Chiu et al., 2005).

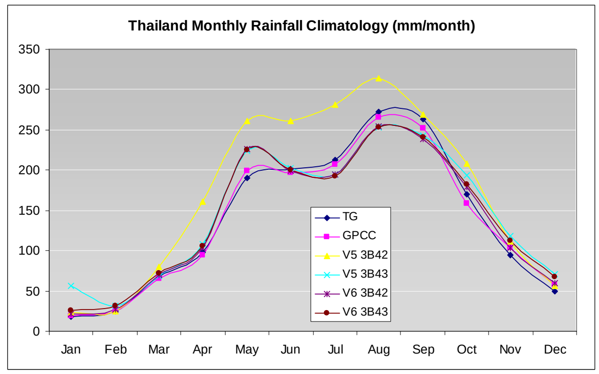

Figure 4. Comparison of Thailand seasonal rainfall climatology. TG and GPCC are computed from 1993-2002. TRMM 3B42 and 3B43 are computed from 1998-2002.

Bias (Algorithm - TG)	TG average	GPCC - TG	V5 3B42 - TG	V5 3B43 - TG	V6 3B42 - TG	V6 3B43 - TG
January	17.55	2.00	-3.10	32.77	-1.74	2.59
February	24.96	-0.66	-5.16	1.55	-2.48	1.69
March	67.39	-1.79	7.95	-3.48	-2.36	-0.47
April	97.71	-3.45	51.19	-1.64	-6.22	-3.96
May	189.96	9.57	51.37	14.20	16.57	15.14
June	201.24	-4.70	52.45	-6.46	-9.79	-9.16
July	213.06	-6.09	83.26	-3.32	-3.68	-5.04
August	272.50	-7.01	50.71	-9.87	-8.56	-10.58
September	262.90	-10.81	19.63	-6.34	-10.76	-8.76
October	169.68	-10.72	19.41	5.39	-9.58	-5.68
November	94.34	9.21	11.92	19.59	4.43	13.38
December	49.30	7.73	2.82	16.43	5.43	13.92

Table 2. The seasonal average TG rain rates and biases from all data sets in mm/month.

Table 3 summarizes the bias, RMSD and MAD between the monthly TG data and other data sets. The 5-year monthly averages of the TG, V5 3B42, V5 3B43, V6 3B42 and V6 3B43 are 143.00, 170.89, 147.03, 139.51 and 142.38 mm/month respectively. The difference between GPCC and TG is small. The V5 TRMM 3B42 is much higher than TG, especially during the rain season (May to September). Since the TRMM 3B43 is a merged gauge and satellite (3B42) product, its bias is relatively small. The estimates from the TRMM V5 algorithm tend to be higher than the TG, while the V6 is lower. Since the TRMM V6 algorithm is improved, the biases are also much reduced. Among all measurements, the V6 3B43 yields the best result in term of statistical errors.

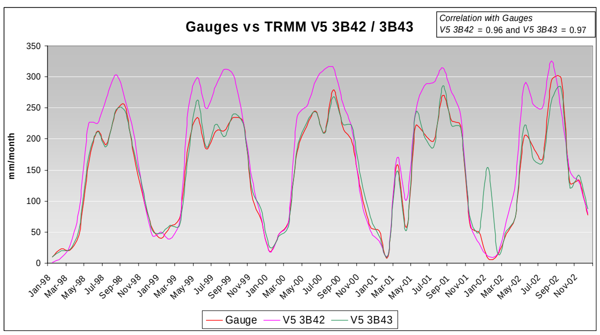

Figure 5a. Time series of average rain rate over Thailand for Thailand gauge, V5 3B42 and 3B43.

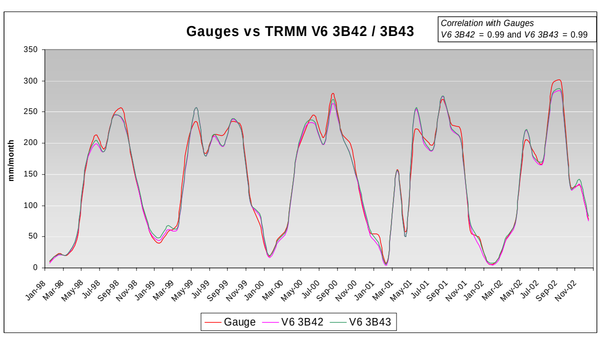

Figure 5b. Same as in Figure 5a, except for V6 data

To examine non-seasonal variations, the season cycle is subtracted from the original monthly data. Figure 6 shows the time series of the monthly non-seasonal rainfall for all data sets from 1998 to 2002. Compared to the V5 TRMM algorithm, the V6 algorithm shows a better correlation with the TG measurement. The correlations of the non-seasonal data between TG and GPCC, V6 3B42, V6 3B43, V5 3B43 and 3B42 are 0.96, 0.92, 0.91, 0.78 and 0.77, respectively. The discrepancy in V5 3B43 for January 2002 clearly reflects an error in V5 3B43 for that month. It is interesting, however, to note that the satellite only estimate of V5 3B42, actually tracks the TG data quite well for that month.

mm/month	Bias	RMSD	MAD
GPCC - TG	-1.39	67.23	8.12
V5 3B42 - TG	27.89	110.85	33.45
V5 3B43 - TG	4.02	81.49	10.95
V6 3B42 - TG	-3.49	75.74	7.83
V6 3B43 - TG	-0.62	72.32	7.51

Table 3. Bias, RMSD and MAD between algorithm and TG rain rates in mm/month. Statistics are computed for the period 1998-2002 except for GPCC which is 1993-2002.

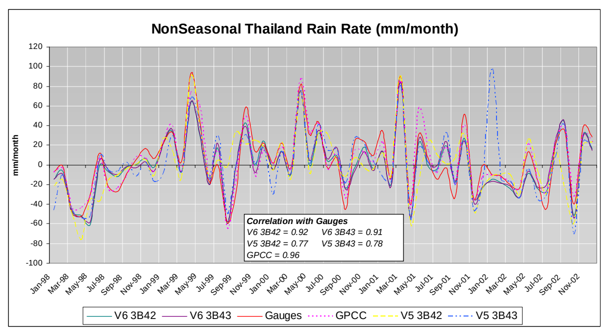

Figure 6. Thailand non-seasonal rainfall

The scatter plots between monthly TG and GPCC, 3B42 and 3B43 are displayed in Figure 7. GPCC is best correlated with TG. Although there is a positive bias (3B42 and 3B43 > TG), there is a tendency of the monthly 3B42 to taper around 5-600 mm/month, and hence there is in fact a negative bias (3B42 < TG) at rain rates higher than around 400 mm/month. The same is true for 3B43, but to a lesser extent. It seems that the satellite measurements cannot measure rain rate higher than 1000 mm/month. This occurs in a coastal pixel of the east region in July and August and in the south region in November and December. Without these two pixels, the average TG becomes lower than GPCC with a positive bias of 1.61 mm/month and RMSD and MAD are also reduced to 61.78 and 7.51.

Figure 8 shows the histogram of all data sets. All histograms are binned using the interval of 10 mm/month. All TRMM and GPCC histograms show a bimodal distribution. The low rain probabilities with rain rates < 10 mm/month, including no rain months, (PL = Pr(RR<10)) are calculated. In general, the V6 algorithms show higher PL than the V5 algorithms. The low rain probability of TG (PL = 0.144) is the highest, followed by V6 3B42 (PL = 0.135), GPCC (PL = 0.122).

To explore the bimodal nature of the monthly rain rates, Figure 9 shows the histogram of TG monthly rainfall for the rain season (May to October) and dry season (November to April). Hence during the rain season, the PL is zero whereas it is 0.27 for the dry season. The maximum rain rate of 1614.9 mm/month for the rain season is higher than that for the dry season (1161.5 mm/month).

The cumulative distribution functions (CDF) of all data sets are computed and shown in Figure 10. There is almost no difference between the V6 algorithms (3B42 monthly and 3B43). Both the V6 and V5 3B43 CDFs cross the TG CDF at around 250 mm/month of around 80%. The CDF of V5 3B42 crosses the TG CDF at around 190 mm/month at higher than 95%. These further illustrate that the TRMM and GPCC overestimates at the general low to mid rain rate range, but under-estimate at the high end of the rain rate distribution.

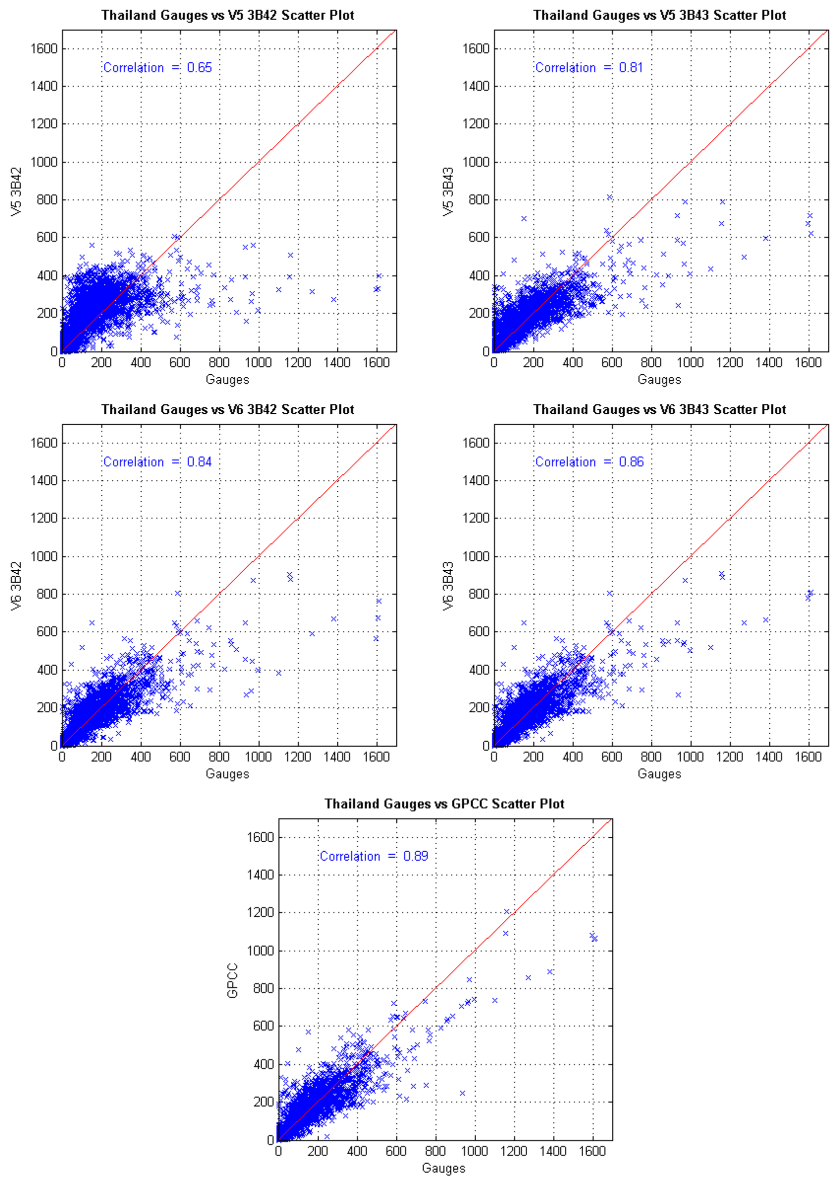

Figure 7. Scatter Plots of TG vs GPCC, TRMM 3B42 and 3B43.

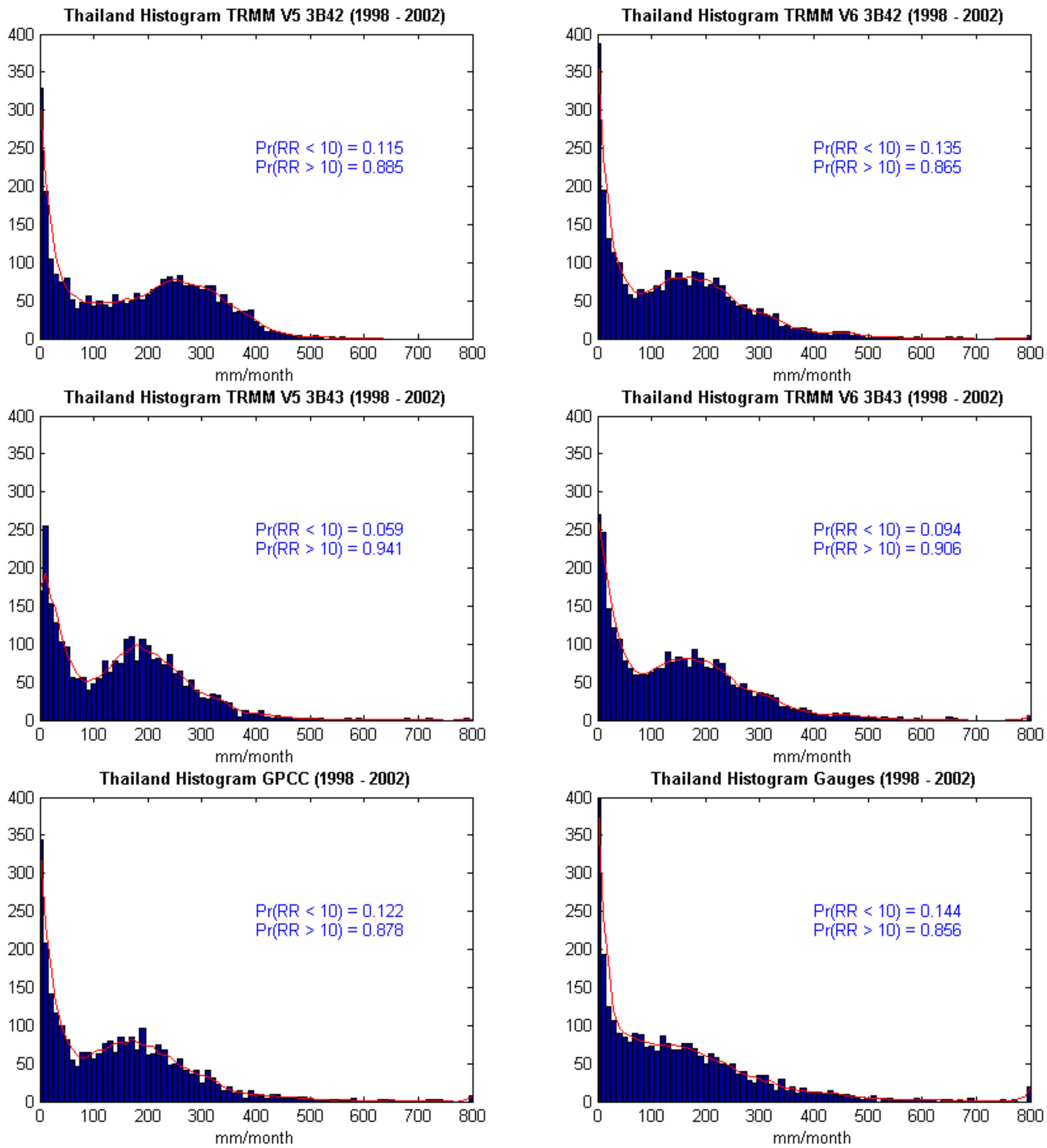

Figure 8. Histogram of each data set

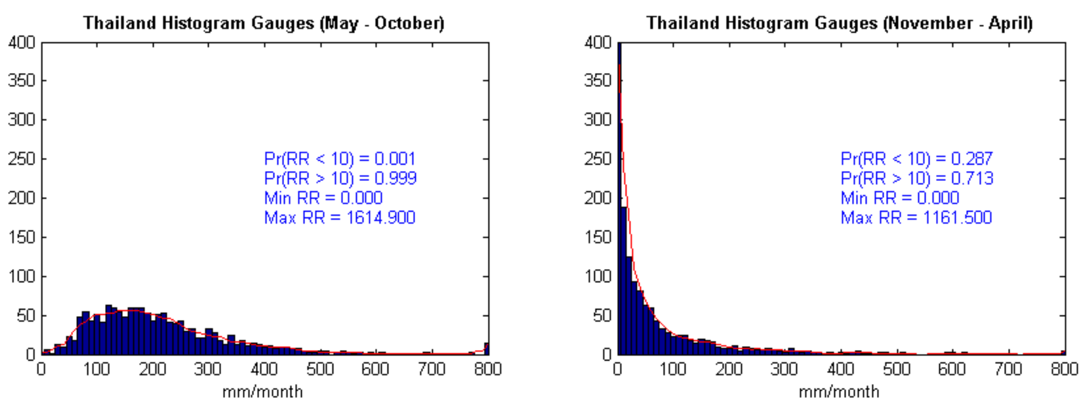

Figure 9. Histogram of rain and dry season from TG

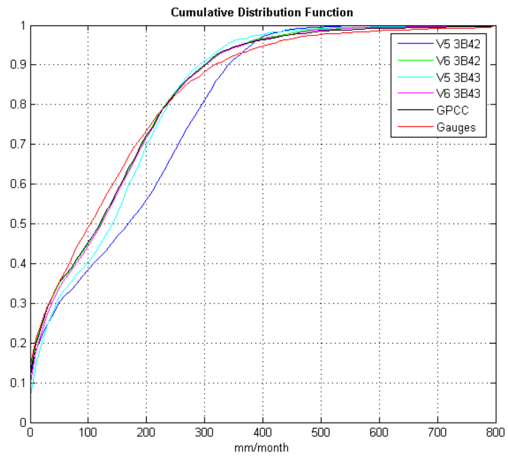

Figure 10. Cumulative Distribution Function (CDF) of all rain rate algorithms

3.3 *Daily Comparison*

In this section, we will focus on the daily products of 3B42 (V5 and V6). Figure 11 shows the TG daily rainfall climatology based on 10 years of record. Although the double peaks in the rain seasons are discernible, the variations at the daily scale are still quite prominent. The 5-year (1998-2002) daily averages for TG, V5 3B42 and V6 3B42 are 4.73, 5.62 and 4.58 mm/day respectively. Table 4 summarizes the bias, RMSD and MAD for the TRMM 3B42 algorithms. The V6 algorithm (3B42) show better correspondence to TG: a low negative bias (-0.15 mm/day) compared to V5 (0.88 mm/day) and a lower MAD (1.78 vs. 2.24). Table 5 summarizes the regional biases and MADs for all five regions. The V6 3B42 is consistently lower than the V5 estimates, and hence shows lower (more negative) biases. Except for the east region, the V6 biases are less than 0.5 mm/day of the TG estimates.

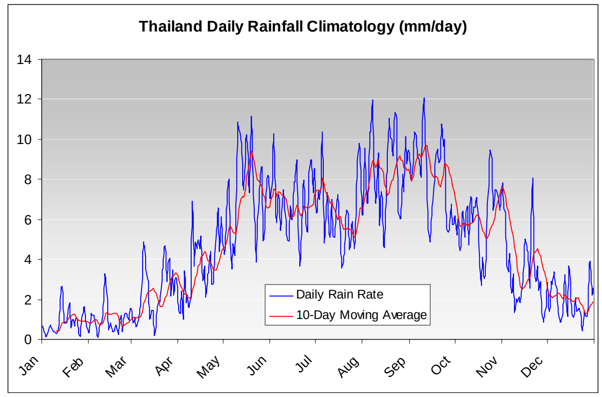

Figure 11. Climatology of Thailand daily rainfall

mm/day	Bias	RMSD	MAE
V5 3B42 – TG	0.88	9.71	2.24
V6 3B42 - TG	-0.15	9.60	1.78

Table 4. Bias, RMSD and MAD between 3B42 and TG. Units in mm/day

mm/day		Center	East	Northeast	North	South
V5 3B42 – TG	Bias	2.46	-0.80	1.29	1.31	0.37
	MAD	3.78	4.65	3.04	3.04	3.74
V6 3B42 - TG	Bias	0.10	-1.58	0.41	0.04	-0.25
	MAD	2.34	4.56	2.35	1.94	3.56

Table 5. Daily bias and MAD for all different regions of Thailand

3B42 V5	ALL	DJF	MAM	JJA	SON
POD	0.92	0.62	0.94	0.97	0.92
FAR	0.35	0.58	0.41	0.29	0.30
CSI	0.62	0.34	0.57	0.70	0.66

3B42 V6	ALL	DJF	MAM	JJA	SON
POD	0.88	0.72	0.90	0.90	0.89
FAR	0.33	0.58	0.38	0.26	0.27
CSI	0.62	0.36	0.58	0.69	0.67

Table 6. POD, FAR and CSI of TRMM 3B42

Skill measures such as the probability of detection (POD), false alarm rate (FAR), critical success index (CSI), are used to examine rain events and the gauge measurements are used for verification (Schaefer 1990). POD is a measure of how well the TRMM algorithms estimate rain events. It is defined as the number of hit (daily grid boxes that correctly estimate rain by the algorithm) divided by the number of rainy pixels (as estimated from TG). The POD considers only the measured rain, but the FAR considers all forecast of rain. If rain was estimated by the algorithm, but did not occur, it is considered as a false alarm. The FAR is the ratio of false alarms divided by the total number of rain forecasts by the algorithm. The CSI is the number of hits divided by the total number of hits, misses and false alarms. For the perfect forecast, POD = 1, FAR = 0 and CSI = 1. The POD, FAR and CSI of the V5 and V6 algorithms for the whole year and in different seasons are calculated and shown in Table 6. The results show that the PODs are higher for the V5 data than for the V6 data. However, the FARs are also higher for the V5, hence the CSI is almost the same for both V5 and V6. All statistics (POD, FAR and CSI) are in general better for the rainy season (JJA-SON) than for the dry season (DJF-MAM). Even though the biases for all the regions are substantially reduced for V6, there is little difference in the CSI.

We next examine the daily rain rate distribution. Figure 12 shows the distribution of the daily rain rates for the V5, V6 and TG data. While the distribution of V6 is quite similar to TG, V5 histogram shows more rain at mid range (5-20mm/day). The rain rates are binned at 0.5 mm/day interval and the probabilities in the (0-0.5 mm/day) rain rate bins are 0.584, 0.493 and 0.411 for TG, V6 and V5. The zero rain rate (RR=0) fractions are calculated to be 0.54, 0.40 and 0.36 for TG, V6 and V5. The conditional rain rates (rain rate when raining) are 10.33, 7.60 and 8.75 mm/day for TG, V6 and V5 3B42, respectively. Hence the V6 algorithm shows improvements, both in terms of the rain probability and conditional rain rate, over the V5 when compared with TG data. Overall, the 3B42 overestimates the rain fraction and underestimates the conditional rain rates.

The cumulative distribution functions of the daily rain rates are shown in Figure 13. While V5 estimates higher rain rates in the general rain rate range, V6 compares much better to TG than V5.

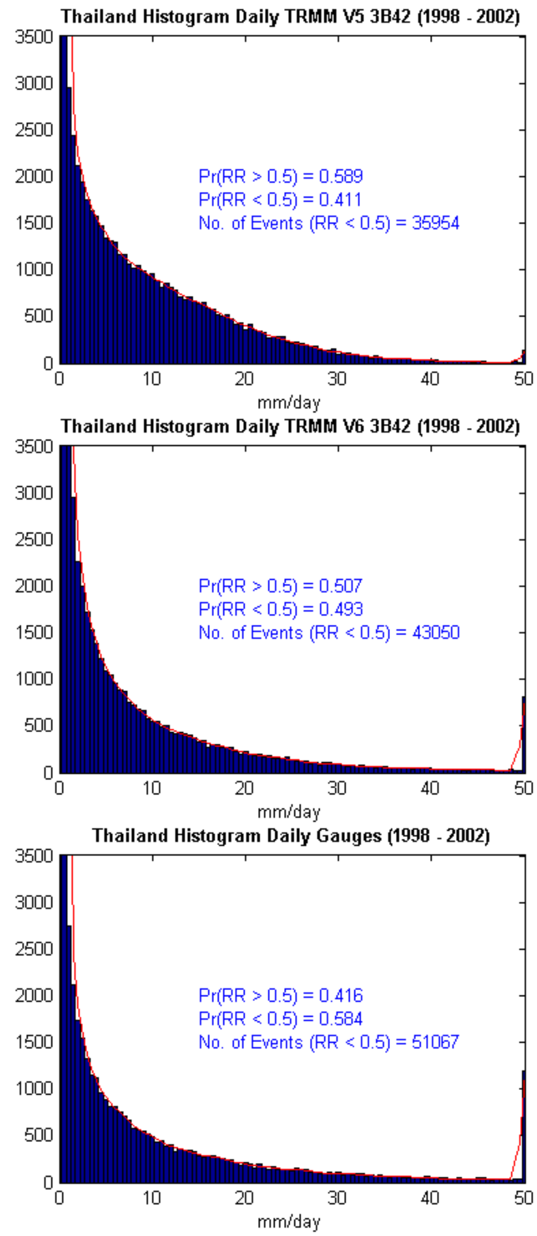

Figure 12. Histogram of TG, V5 and V6 3B42

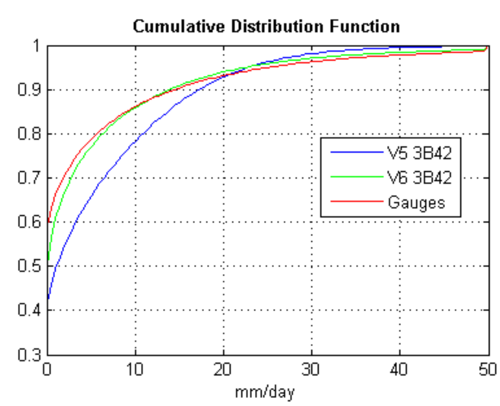

Figure 13. CDF of TG, V5 and V6 3B42

To further examine the relation between TG and TRMM rain rates, Figure 14 shows the scatter plot of TG and V5 and V6 rain rates. The correlations between TG and V5 and V6 are 0.37 and 0.44, respectively. A series of calculations were performed to investigate optimal averaging time between V5, V6 and TG. Figure 15 shows correlation coefficients between TG and V5 and V6 algorithms for different temporal and spatial averaging. The correlation coefficients increase as the averaging time is increased from 1 day to 10 days for each 1 degree box. When the averaging area is increased to the whole of Thailand, the correlation increases sharply for averaging periods of 2-3 days, and stabilizes beyond 3 days. Hence an optimal averaging period is about 3 days for spatial averages of roughly 50 1°x1° grid (or ~400,000 km^2) boxes.

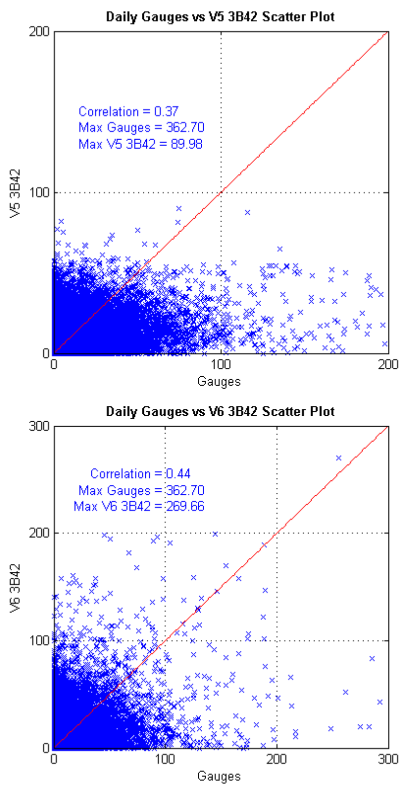

Figure 14. Scatter plots of TG vs V5 and V6 3B42

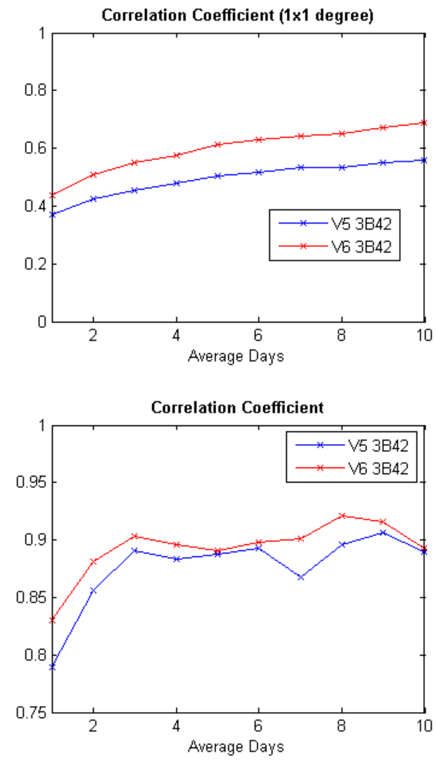

Figure 15. Correlation coefficients between TG and TRMM rain rates over Thailand for different averaging times.

4. CONCLUSION

An examination of the Thailand gauges shows two distinct seasons: dry and rain seasons. The histogram of monthly rain rates shows a bimodal distribution. These modes are attributed to the rain and dry seasons, respectively. The rain season starts in May and progresses southeast to northwest. The maximum rainfall, however, occurs in August for the north and northeast regions, in September for center and east regions and in November for the south region. The retreat of rainfall follows the movement of the ITCZ and goes from north to south.

Analyses of monthly data between TG and GPCC yield very low bias, RMSD and MAD. The V5 TRMM 3B42 is much higher than TG. An outliner for January 2002 in V5 3B43 is removed in the V6 data, suggesting the improved quality of input data and information in the satellite estimates. There is also little difference between V6 3B42 and 3B43, consistent with the results of Chiu et al. (2005b). The bias, RMSD and MAD from V6 3B43 is smallest compared to the other algorithms, including GPCC.

The scatter plots show that the satellite measurements are incapable of capturing some of the heavy rain rates in excess of 1000 mm/month. These TG rain rates are limited to two grid boxes. If these two grid boxes are excluded in the calculation, the biases are improved for GPCC.

In daily rainfall comparisons, the V6 3B42 algorithms show less biases compared to V5. Although the FAR for the V6 is slightly decreased, the POD is also decreased, hence the CSI is basically unchanged.

The V6 is better correlated with TG (0.44) than V5 (0.37). The distribution of the daily rain rates for V6 is quite similar to TG while the V5 has more rain in the range 5-20mm/day. To examine the spatial and temporal structure of the algorithms, the correlation between TG and the algorithms were computed using different temporal averages for the different regions. To achieve a correlation coefficient of 0.8, an averaging time of 2-3 days for the whole of Thailand (~50 grid boxes) is required, whereas the averaging time is 8-10 days for the central part of Thailand, which has an area of ~8 grid boxes. Further studies are needed to quantify the space/time correlation of satellite rainfall and TG data.

The V6 TRMM algorithms show improvement over the V5, in terms of the bias, RMSD, and MAD. The daily algorithm also shows improved correlation with TG data. However, while the FAR for daily rainfall is decreased, the POD is also decreased, hence the skill score is relatively unchanged. The quality of the satellite rainfall measurements needs to be continually evaluated and further studies are required to quantify the use of satellite measurement in Thailand.

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