Comparison the Estimate Rainfall from Global Satellite Mapping of Precipitation (GSMaP) to Ground-based Precipitation data over Thailand

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Abstract

This paper studied the verification statistics used in evaluating of the estimate rainfall from satellite over Thailand during 2000-2010 periods. The satellite data from GSMaP_MVK (TRMM/TMI, Aqua/AMSR-E, ADEOS-II/AMSR, DMSP/SSMI) have resolution grid about 0.1degrees from the Japan Aerospace Exploration Agency (JAXA), rainfall observed from stations of Thailand Meteorological Department (TMD). The assessment of the accuracy GSMaP_MVK has two experiments, the first experiment studied the estimated rainfall over all seasons, the summer (mid-February to mid-May), rainy (mid-May to mid-October) and winter (mid-October to mid February). The second examined the estimated rainfall from tropical cyclones. Verification all seasons showed that GSMaP_MVK better performs in all seasons of the probability of detection (*POD)* and the threat score (*TS)* are quiet high value 0.94 and 0.89, the false alarm ratio (*FAR)* and probability of false detection *(POFD)* are quiet low value 0.06 and 0.08. The relationship, both data of the correlation coefficient (*CC*) is 0.80, the mean absolute error (*MAE*) is 1.55, the root mean square error (*RMSE*) is 2.51. The second verified the estimated rainfall from GSMaP_MVK in typhoon "Xangsan" moved through during 22 September to 4 October 2006 of *POD, TS, FAR and PODF* are average value 0.87, 0.78, 0.11 and 0.48, and also typhoon "Ketsana" moved through during 23-29 September 2009 of *POD*, *TS*, *FAR and PODF* are average value 0.90, 0.79, 0.16 and 0.57. Thus, GSMaP_MVK is under-estimated rainfall form observation that is slightly the estimated rainfall with the correlation coefficient of 0.67, 0.69,0.85, 0.80 over the area. GSMaP_MVK showed the statistical verification at point to point of *POD* and *TS* have an evaluating of the estimated daily rainfall from GSMaP_MVK is perfect in rainy season, and also are quite weak in summer season. However, from the results indicated a GSMaP_MVK need to account rain to calculated investigating. Therefore, GSMaP_MVK algorithm is a good performance to estimate rainfall in the area.

Key words: GSMaP_MVK, Estimated Rainfall from Satellite.

1. Introduction

At present, detector technology has developed rapidly in the applications of meteorological satellite estimated rainfall. The sensor consists of an infrared detector used to determine cloud top temperature relative to the amount of rain, microwave radiation one of the sensors can be reflected, absorbed and distributed by the incorporation of water vapor in the air caused by the reaction of water vapor and ice crystals that release their energy can estimate the amount of rain in the sky. We also studied the estimated rainfall from meteorological satellite data compared with the rain gauge measurements from the stations so called the quantitative precipitation estimation (QPE). The paper studied the estimation rainfall from meteorological satellite of the geostationary meteorological satellite (GMS) data in Thailand by the relationship between cloud top temperature from satellite GMS-4 and GMS-5 on infrared (IR) channel data with the automatic rain gauge rainfall by considering only the vertical cloud formation caused by the convection of the air, which has proportional rainfall to the height of cloud top[4][11]. The estimated rainfall from GMS-5 data related to the rainfall from observed by microwave [3]. The estimated rainfall from GSMaP_MVK+ (GSMaP_MVK+ product uses the estimated rainfall from the AMSU-B is provided by the NOAA) comparison with rain gauge observations over the Nepal Himalaya that used two levels are the first is the whole country[7][8], and the second is physiographies regions, the estimated rainfall in Thailand using FY-2C infrared data [9][12], and also the studied monthly adjustment of global satellite mapping of precipitation (GSMaP) data over the VuGia-ThuBon river basin in the central Vietnam uses an artificial neural network [5][6]. This paper proposed to use daily GSMaP products during 2000-2010 for validation rain gauge stations in Thailand. The technique study can be separated into the first part study of the estimated rainfall over all seasons, in each season as the summer (mid-February to mid-May), rainy (mid-May to mid-October) and winter (mid-October to mid February). The second is to study in each case of the tropical cyclone move throughout the area during 22September to 4 October 2006 and 22-29 September 2009.

2. Study area and Data

2.1 Study area

Thailand is located at latitude 20.27^oN to 5.37^oN and longitude 97.22^oE to 105.37^oE, a total area of approximately 513,115 kilometer squares. Thailand is naturally divided into four topographical regions: the North, the Central Plain or Chao Phraya River basin, the Northeast or the Korat Plateau, and the South or Southern Isthmus. The North is a mountainous region characterized by natural forests, narrow, alluvial valleys, ridges and deep. Central Thailand, the basin of the Chao Phraya River, is a lush, fertile valley. The Northeastern region is an arid region characterized by a rolling surface and undulating hills. The Southern region is hilly to mountainous.

2.2 Satellite Data

The GSMaP is one of the leading products to provide hourly rain rate estimates with a resolution of 0.1 degrees longitude by 0.1 degrees latitude for the entire world. Major inputs to GSMaP are observations from microwave radiometers including the Tropical Rainfall Measuring Mission (TRMM) Imager and Sounder (SSMIS), and the Advanced Microwave Sounding Unit (AMSU). Over land, the scattering signals measured at higher frequency channels (mainly between 85 and 90 GHz) are used for rain retrieval [6]. The microwave radiometers do not cover the entire globe in one hour. To fill the gap in the microwave observations, cloud moving vectors are derived from infrared imagery of geostationary meteorological satellites. The passive microwave radiometer data used in an hourly GSMaP_MVK (TRMM/TMI, Aqua/AMSR-E, ADEOS-II/AMSR, DMSP/SSMI) have resolution grid about 0.1degrees [10][13].

2.3 Ground based data

The rain gauge stations network of Thai Meteorological Department (TMD) compose of the surface stations, Ao-meteorological stations and Hydro-meteorological stations (see figure 1).

3. Methodology

The standard comparison methods for estimating rainfall involve computation are following:

a) Mean Absolute Error (*MAE*) measures the average of the absolute deviation between the estimations and observations. Absolute error retains the differences in magnitude that would otherwise be reduced because positive and negative differences would cancel each other to some degree. The range of MAE is 0 to infinity and the perfect score is 0.

b) Root Mean Square Error *(RMSE)* is similar to MAE measure the mean error magnitude, only it gives greater weight to the larger error because the differences are square before adding. The range of *RMSE* is 0 to infinity and the perfect score is 0.

c) The correlation coefficient (*CC*) also called Pearson's product moment correlations. The coefficient correlation is a measure of the strength and direction of the linear relationship between two variables. The correlation coefficient may take any value between -1.0 and +1.0.

d) The probability of detection (*POD*) or simply the hit rate is the fraction of the observed 'yes' events that were also forecasted 'yes' events. The POD ranges from 0 to 1 and a score of 1 meaning perfect forecast. This score is sensitive to hits, but it ignores the false alarms. It is rattling sensitive to the climatological frequency of the result.

e) The false alarm ratio (*FAR)* is a touchstone of the fraction of predicted 'yes' events that actually did not happen. This score ranges from 0 to 1 and a score of 0 implies perfect forecast. This score is sensitive to false alarms, but it ignores the missed events. It is very sensitive to the climatological frequency of the event.

f) The probability of false detection (*POFD*) or in simple words the false alarm rate is fraction of the observed 'no' events microwave imager (TMI), the Microwave Scanning Radiometer for the Earth Observing System (AMSR-E), the Special Sensor Microwave Imager (SSMI), the Special Sensor Microwave that were incorrectly forecast as 'yes' events. This score ranges from 0 to 1 and the perfect score is 0. While it is sensitive to false alarms, it ignores the missed events. It includes the correct negatives in place of hits (in FAR).

g) The threat score (*TS*) or critical success index (*CSI*) tells us how well did the forecast 'yes' events correspond to the observed 'yes' events. This score ranges from 0 to 1; where 0 indicates no skill and 1 indicates a perfect score. It is the most accurate when correct negatives have been removed from consideration, i.e., the TS is only concerned with forecasts that count. This score is sensitive to hits while it penalizes both misses and false alarms.

A series of statistics, scores are computed based on a categorical contingency table (table 1.) where an event (yes) is defined by rainfall greater than or equal to the specified threshold (0.1mm/day); otherwise, it is a non event (no)

Table 1: Contingency table for categories estimates of a point to point event. Where *a*, *b*, *c* and *d* are the number of events observed to occur above a threshold

	Observed		
Estimate	Yes	No	Total
Yes	*a* (hit)	*b* (false alarm)	*a*+*b*
No	*c* (miss)	*d* (correct rejection)	*c*+*d*
Total	*a*+*c*	*b*+*d*	*a*+*b*+*c*+*d*=*n*

Table 2: Description of the verification statistics used in evaluating of the estimate rainfall from satellite

1. Mean Absolute Error (*MAE*) $MAE = \frac{1}{N}\sum_i |Y_i - O_i|$
2. Root Mean Square Error (*RMSE*) $RMSE = \sqrt{\frac{1}{N}(Y_i - O_i)}$
3. The correlation coefficient (*CC*) $CC = \frac{\sum_{i=1}^{N}(Y_i-\bar{Y})(O_i-\bar{O})}{\sqrt{\sum_{i=1}^{N}(Y_i-\bar{Y})^2 \sum_{i=1}^{N}(O_i-\bar{O})^2}}$

   Where Y_i indicates the estimated value at the point or grid box in i, O_i indicates the observed values and N is the number of samples.

4. Probability of detection (hit rate) $POD = \frac{a}{a+c}$
5. False alarm ratio (FAR) $FAR = \frac{b}{a+b}$
6. Probability of false detection (false alarm rate) $POFD = \frac{b}{b+d}$
7. Threat score (critical success index) $TS = \frac{a}{a+b+c}$

4. Results and Discussion

4.1 Assessment of the accuracy of the estimated rainfall from meteorological satellites over Thailand. The technique verified the quantitative estimation rainfall from satellite over Thailand that is conducted by comparing the estimated rainfall with rain gauge observation data during 2000-2010. GSMaP_MVK data are binary format then we can use the technique converted binary format data to the American Standard Code for Information Interchange (ASCII) format data that was written by script program command on Unix systems. The script program can write the located rain of GSMaP_MVK data in latitude and longitude at the same rain gauge observations by point to point.

Figure 2, the results showed the relationship of GSMaP_MVK daily rainfall to daily rainfall from observations that have a good relationship. The estimated rainfall from observation quit higher more than the estimated rainfall from satellite.

Table 2, The categories estimates of a point to point event are hit (*a*), false alarm (*b*), miss (*c*) and correct rejection (*d*) are a number of events observed to occur above threshold in over all seasons and also each season (summer, rainy and winter) which were calculated of the verification statistics used in evaluating of the estimate rainfall calculated *POD*, *FAR*, *POFD* and *TS* by input all data from table 4 and 6 for the equation. The results showed that the probability of detection (*POD*) the hit rate is the fraction of the observed 'yes' events that were also estimated 'yes' events. The *POD* ranges from 0 to 1 and a score of 1 meaning perfect forecast. In all season, *POD* showed quit high is 0.94 in 2008. The threat score (*TS*) ranges from 0 to 1; where 0 indicates no skill and 1 indicates a perfect score, is higher value 0.89 in 2000 and 2008. False alarm ratio (*FAR*) is a measure of the fraction of predicted 'yes' events that actually did not occur. This score ranges from 0 to 1 and a score of 0 implies perfect forecast showed lower value 0.06 in 2006. The probability of false detection (*POFD*) is fraction of the observed 'no' events that were incorrectly forecast as 'yes' events. This score ranges from 0 to 1 and the perfect score is 0, showed lower value 0.08 in 2003.

Table 3, the relationship estimated daily rainfall from meteorological satellite data to the measures daily rainfall from rain gauge were investigated by statistics parameters, the results showed that R^2 is 0.6451, *CC* is 0.80, *MAE* is 1.55 and *RMSE* is 2.51, in the summer have R^2 is 0.7305, *CC* is 0.85, *MAE* is 1.14 and *RMSE* is 1.95, in rainy have R^2 of 0.4788, *CC* is 0.69, *MAE* is 2.06 and *RMSE* is 2.89, and in winter have the R^2 is 0.4436, *CC* is 0.67, *MAE* is 1.20 and *RMSE* is 2.37. The relationship between both the data showed that the linear regression of R^2 is low (0.404) and a maximum (0.73). The coefficient of correlation as the *CC* is a minimum value of 0.67 in winter season, and a maximum of 0.85 on the season in figure 3 (*a*) to (*d*).

4.2 Assessment of the accuracy of the estimated rainfall from meteorological satellites over Thailand in each season.

Table 7, the summer case of the results showed that the *POD* higher value 0.59, *TS* higher value 0.39, *FAR* lower value 0.44 and *POFD* lower value 0.09 (table 5). Rainy case, the results showed that the *POD* higher value 0.59, TS higher value 0.39, *FAR* lower value 0.44 and *POFD* lower value 0.09 (in table 7) and the winter case, the results showed that the *POD* higher value 0.59, *TS* higher value 0.39, *FAR* lower value 0.44 and *POFD* lower value 0.09 (in table 7).

4.3 Assessment of the accuracy of the estimated rainfall from meteorological satellite over Thailand in tropical cyclone case.

Case 1, Consideration the estimated rainfall from satellite of typhoon "Xangsane" moved through during 22 September to 4 October 2006 found that the verification statistics used in evaluating of the estimate rainfall from satellite, *POD* and *TS* higher value are 0.97and 0.94, *FAR* and *POFD* lower value 0.08 (in table 9). The relationship between both the data showed that the linear regression of R^2 is 0.70 in figure 4 (*e*), the coefficient of correlation is 0.67, *MAE* is 1.20 and *RMSE* is 2.37.

Case 2, The case of typhoon "Ketsana" moved through during 23-29 September 2009, the results showed that *POD* and *TS* higher value are 0.99 and 0.96, *FAR* and *POFD* lowest value is 0.13 (in table 11). The relationship between both the data showed that the linear regression of R^2 is 0.8462 in figure 4 (*f*), the coefficient of correlation is 0.92, *MAE* is 2.01 and *RMSE* is 2.12.

From the studied of the estimated daily rainfall from satellite all seasons found that the relationship, both data is quite close in all seasons and rainy season except in the summer because of the moderate and heavy rain in the only lower southern part and most upper Thailand clear weather. The verifiable statistics used in evaluating of the estimate rainfall from satellite showed the most *POD* and *TS* have a good values are 0.87 and 0.75 over Thailand. In case rainfall from the tropical cyclone moved through the area during 22 September 2006 to 4 October 2006 that a quite high an average value of *POD* and *TS* are 0.87 and 0.78, a quite low an average value of *FAR* and *POFD* are 0.11 and 0.48. In case the tropical cyclone moved through the area during 23 - 29 September 2009 that an average value of *POD* and *TS* are 0.90 and 0.79, and a quite low an average value of *FAR* and *POFD* are 0.16 and 0.57. The study to estimate the amount of rainfall of meteorological satellites *GSMaP_MVK* in the Chao Paya basin gives the result the *POD* 0.94, *FAR* 0.79, *CC* is 0.7 and RMSE is 14.23 [1]. The studied the verification of GSMaP_MVK+ rainfall estimate over the central Himalayas, results showed that quiet equal 1.0, *CC* of 0.79, *RMSE* of 4.8 and *ME* (*bias*) of -2.6 [8][12]. Then, The technique use GSMaP_MVK estimate rainfall from this paper indicates that an accuracy rainfall from satellite can use in the area or the GSMaP_MVK algorithm is a good performance to estimate rainfall.

5. Conclusions

In this paper, the verification of daily rainfall of meteorological satellite and observed rainfall from TMD over Thailand during 2000-2010. GSMaP_MVK is under-estimated rainfall form observation that is slightly the estimated rainfall with the correlation coefficient of 0.67, 0.69,0.85, 0.80 (in table 3) over the area. GSMaP_MVK showed the statistical verification at point to point of *POD* and *TS* have an evaluating of the estimated daily rainfall from GSMaP_MVK is perfect in rainy season, and also are quite weak in summer season. Then, the results indicated a GSMaP_MVK need to account rain. Therefore, GSMaP_MVK algorithm is a good performance to estimate rainfall in the area.

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Table 3: The verification statistics used in evaluating of the estimate rainfall from satellite.

Region	Season	*A*	R^2	*CC*	*MAE*	*RMSE*
Over Area	All	0.9394	0.6451	0.80	1.55	2.51
	Summer	0.9294	0.7305	0.85	1.14	1.95
	Rainy	0.9681	0.4788	0.69	2.06	2.89
	Winter	0.8030	0.4436	0.67	1.20	2.37
Case 1	Ty "Xangsane"	0.9823	0.7000	0.84	2.61	3.11
Case 2	Ty "Kitsanae"	1.2095	0.8464	0.92	2.01	2.12

Table 4: Contingency table for categories estimates of a point to point event during 2000-2010.

Year	Overall seasons (12 Months)					Summer (FMAM)				
	Hit	False alarm	Miss	Correct negative	Total	Hit	False alarm	Miss	Correct negative	Total
2000	38,796	3,660	1,098	1,098	44,652	1,277	1,020	1,232	8,813	12,342
2001	29,565	3,650	5,840	5,475	44,530	1,302	1,014	1,211	8,713	12,240
2002	35,040	3,650	4,380	1,460	44,530	1,098	1,021	1,119	9,002	12,240
2003	13,505	1,825	9,490	19,710	44,530	942	954	1,134	8,890	12,240
2004	27,084	3,294	2196	12,078	44,652	1,201	1,019	1,232	8,890	12,342
2005	24,455	8,030	2,555	9,490	44,530	965	1,032	1,201	9,042	12,240
2006	38,325	4,380	1,460	365	44,530	972	1,087	1,098	9,083	12,240
2007	22,630	5,110	1,825	14,965	44,530	997	1,008	1,103	9,132	12,240
2008	36,966	2,562	2,196	2,928	44,652	1,224	1,034	1,231	8,853	12,342
2009	27,010	2,555	9,125	5,840	44,530	1,281	1,012	1,232	8,713	12,240
2010	29,200	4,745	3,285	7,300	44,530	1,494	1,276	1,108	8,362	12,240
Avg.	29,325	3,951	3,950	7,337	44,563	1,159	1,043	1,173	8,863	12,268

Table 5: Description of the verification statistics used in evaluating of the estimate rainfall from satellite during 2000-2010.

Year	Overall seasons (12 Months)				Summer (FMAM)			
	POD	FAR	TS	POFD	POD	FAR	TS	POFD
2000	0.91	0.09	0.89	0.77	0.56	0.44	0.36	0.10
2001	0.89	0.11	0.76	0.40	0.56	0.44	0.37	0.10
2002	0.91	0.09	0.81	0.71	0.52	0.48	0.34	0.10
2003	0.88	0.12	0.54	0.08	0.50	0.50	0.31	0.09
2004	0.89	0.11	0.58	0.21	0.54	0.46	0.35	0.10
2005	0.75	0.25	0.70	0.46	0.48	0.52	0.30	0.10
2006	0.90	0.10	0.87	0.92	0.47	0.53	0.31	0.11
2007	0.82	0.18	0.77	0.25	0.50	0.50	0.32	0.10
2008	0.94	0.06	0.89	0.47	0.54	0.46	0.35	0.10
2009	0.91	0.09	0.70	0.30	0.56	0.44	0.36	0.10
2010	0.86	0.14	0.78	0.39	0.54	0.46	0.39	0.13
Avg.	0.87	0.12	0.75	0.45	0.52	0.47	0.34	0.10

Table 6: Contingency table for categories estimates of a point to point event during 2000-2010.

Year	Rainy (JJAS)					Winter (ONDJ)				
	Hit	False alarm	Miss	Correct negative	Total Observed	Hit	False alarm	Miss	Correct negative	Total Observed
2000	6,110	1,740	1,970	2,624	12,444	1,387	1,045	1,247	8,867	12,546
2001	6,230	1,764	1,800	2,650	12,444	1,328	1,091	1,211	8,916	12,546
2002	6,321	1,600	1,901	2,622	12,444	1,298	1,021	1,219	9,008	12,546
2003	6,000	1,670	1,974	2,600	12,444	1,195	1,007	1,134	9,210	12,546
2004	5,970	1,777	1,900	2,597	12,444	1,201	1,119	1,238	8,988	12,546
2005	6,123	1,654	1,943	2,524	12,444	1,154	1,032	1,201	9,159	12,546
2006	5,894	1,932	1,823	2,595	12,444	1,192	1,187	1,198	8,969	12,546
2007	6,231	1,599	1,820	2,594	12,444	1,179	1,108	1,103	9,156	12,546
2008	5,999	1,743	1,837	2,665	12,444	1,231	1034	1,231	8,050	12,546
2009	6,159	1,734	1,953	2,598	12,444	1,281	1,012	1,232	9,021	12,546
2010	6,113	1,756	1,974	2,601	12,444	1,187	1,178	1,152	9,031	12,546
Avg.	6,105	1,724	1,900	2,606	12,444	1,239	1,076	1,197	8,943	12,546

Table 7: Description of the verification statistics used in evaluating of the estimate rainfall from satellite during 2000-2010.

Year	Rainy (JJAS)				Winter (ONDJ)			
	POD	FAR	TS	POFD	POD	FAR	TS	POFD
2000	0.78	0.22	0.62	0.40	0.57	0.43	0.38	0.11
2001	0.78	0.22	0.64	0.40	0.55	0.45	0.37	0.11
2002	0.80	0.20	0.64	0.38	0.56	0.44	0.37	0.10
2003	0.78	0.22	0.62	0.39	0.54	0.46	0.36	0.10
2004	0.77	0.23	0.62	0.41	0.52	0.48	0.34	0.11
2005	0.79	0.21	0.63	0.40	0.53	0.47	0.34	0.10
2006	0.75	0.25	0.61	0.43	0.50	0.50	0.33	0.12
2007	0.80	0.20	0.65	0.38	0.52	0.48	0.35	0.11
2008	0.77	0.23	0.63	0.40	0.54	0.46	0.35	0.10
2009	0.78	0.22	0.63	0.40	0.56	0.44	0.36	0.10
2010	0.78	0.22	0.62	0.40	0.50	0.50	0.34	0.12
Avg.	0.78	0.22	0.63	0.39	0.53	0.46	0.35	0.12

Table 8: Contingency table for categories estimates of a point to point event during 22 September to 4 October 2006.

Date	Hit	False alarm	Miss	Correct negative
22 SEP 2006	96	10	7	9
23 SEP 2006	37	5	26	54
24 SEP 2006	62	14	5	41
25 SEP 2006	106	10	3	3
26 SEP 2006	74	7	25	16
27 SEP 2006	101	7	6	8
28 SEP 2006	105	12	4	1
29 SEP 2006	62	12	17	31
30 SEP 2006	67	22	7	26
1 OCT 2006	74	9	6	33
2 OCT 2006	115	2	5	0
3 OCT 2006	81	10	16	15
4 OCT 2006	96	10	12	4

Table 9: Description of the verification statistics used in evaluating of the estimate rainfall from satellite during 22 September to 4 October 2006.

Date	POD	FAR	TS	POFD
22 SEP 2006	0.93	0.09	0.84	0.52
23 SEP 2006	0.58	0.11	0.54	0.08
24 SEP 2006	0.92	0.18	0.76	0.25
25 SEP 2006	0.97	0.08	0.89	0.76
26 SEP 2006	0.74	0.08	0.69	0.30
27 SEP 2006	0.94	0.06	0.88	0.46
28 SEP 2006	0.96	0.10	0.86	0.92
29 SEP 2006	0.78	0.16	0.68	0.27
30 SEP 2006	0.90	0.24	0.69	0.45
1 OCT 2006	0.92	0.10	0.84	0.18
2 OCT 2006	0.95	0.01	0.94	1.0
3 OCT 2006	0.83	0.10	0.75	0.40
4 OCT 2006	0.88	0.09	0.81	0.71
Avg.	0.87	0.11	0.78	0.48

Table 10: Contingency table for categories estimates of a point to point event during 23-29 September 2009.

Date	Hit	False alarm	Miss	Correct negative
23 SEP 2009	80	23	4	15
24 SEP 2009	104	13	1	4
25 SEP 2009	117	1	3	1
26 SEP 2009	108	10	2	2
27 SEP 2009	80	13	9	20
28 SEP 2009	32	19	15	56
29 SEP 2009	48	11	9	54
Avg.	81	13	6	22

Table 11: Description of the verification statistics used in evaluating of the estimate rainfall from satellite during 23-29 September 2009.

Date	POD	FAR	TS	POFD
23 SEP 2009	0.95	0.22	0.75	0.61
24 SEP 2009	0.99	0.11	0.88	0.76
25 SEP 2009	0.97	0.01	0.96	1.0
26 SEP 2009	0.98	0.08	0.90	0.83
27 SEP 2009	0.90	0.14	0.78	0.39
28 SEP 2009	0.68	0.37	0.57	0.25
29 SEP 2009	0.84	0.19	0.71	0.17
Avg.	0.90	0.16	0.79	0.57

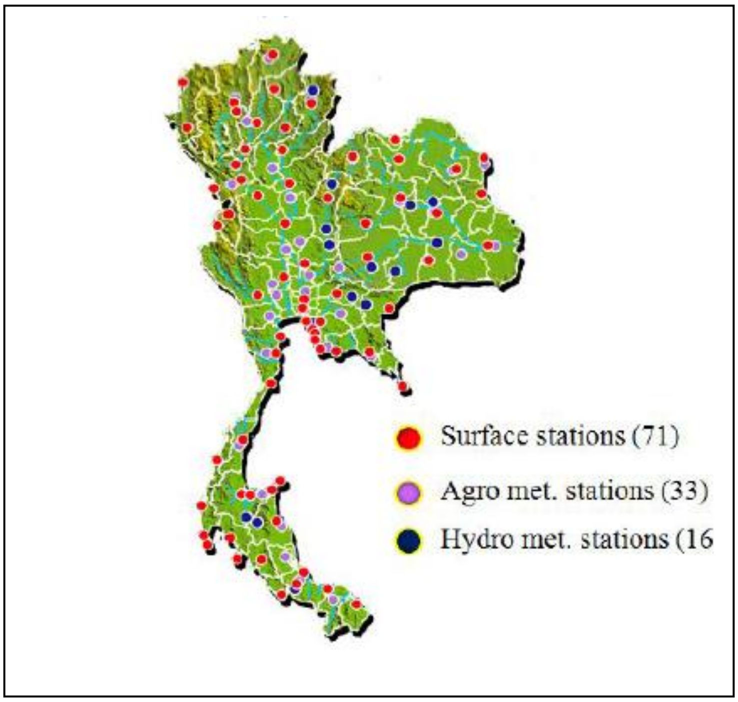

Figure 1: Rain gauge network of Thai Meteorological Department.

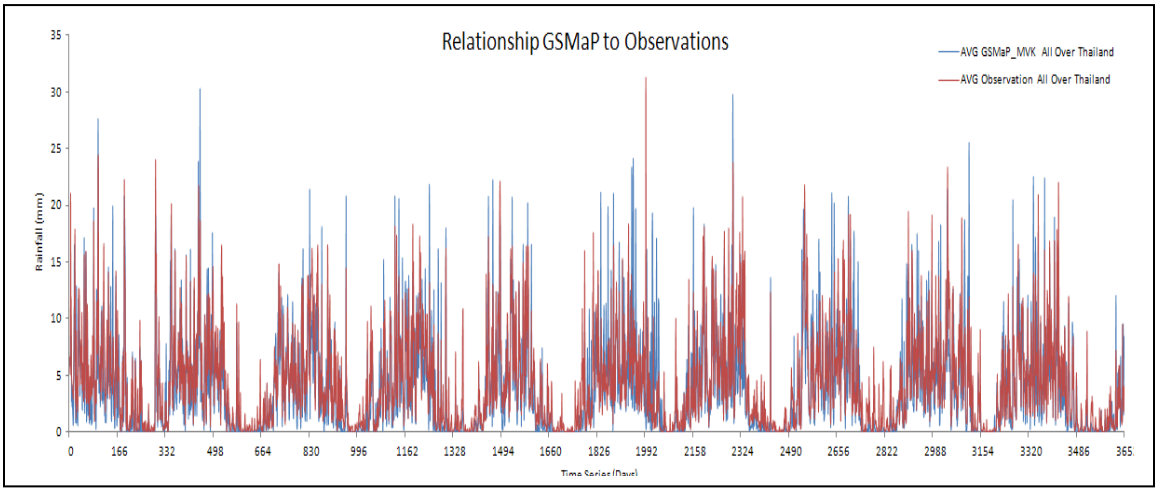

Figure 2: Time series correlation the daily rainfall from GSMaP_MVK to daily rainfall from rain gauge observations during 2000- 2010 over all seasons whole Thailand.

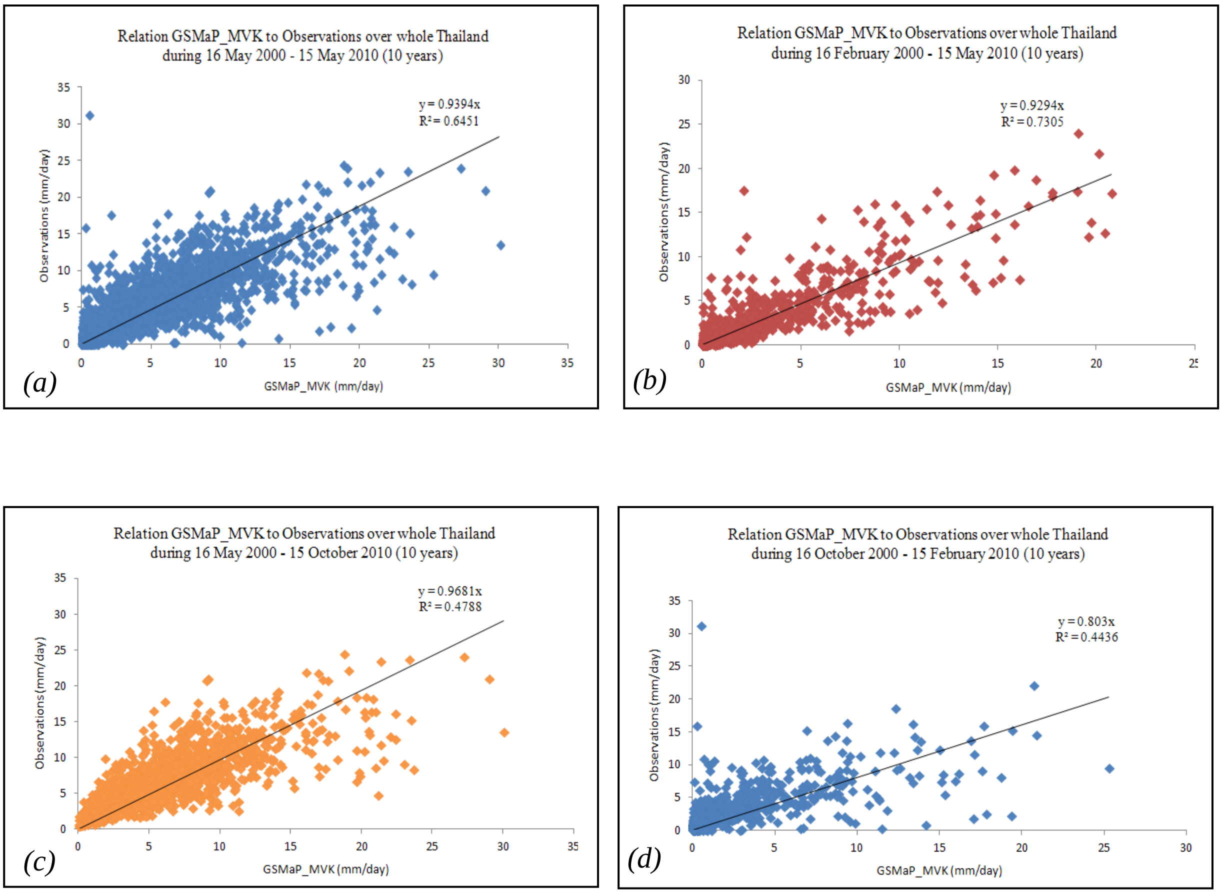

Figure 3: Relation of daily rainfall GSMaP_MVK to Observations over all seasons whole Thailand during 2000 – 2010 periods (*a*), the relation GSMaP_MVK to Observations in the summer season during 16 February to 15 May (*b*), the relation GSMaP_MVK to Observations in the rainy season during 16 May to 15 October (*c*), the relation GSMaP_MVK to Observations in the winter season during 16 October to 15 February (*d*).

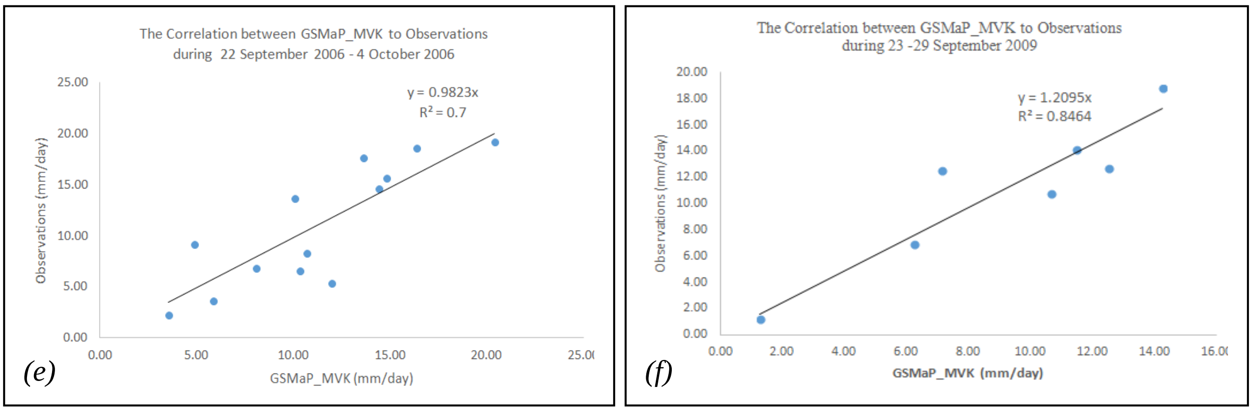

Figure 4: The Correlation between GSMaP_MVK to Observations during 22 September 2006 - 4 October 2006 (*e*) and the Correlation between GSMaP_MVK to Observations during 23-29 September 2009 (*f*).