Assessment of near-real-time satellite-based precipitation over Thailand

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***Abstract*— Satellite-based precipitation products are publicly available and provide continuous series of high temporal and spatial resolution data especially for regions with limited rain gauge. However, satellite-based precipitation is derived from microwave, near infrared and radar signals thus they normally contain bias. Thailand located in the tropical zone and has been affected by floods and droughts frequently. Precipitation data are very important in assessment of water-related disasters. Although there is a good rain gauge network in Thailand, in many parts of the country, there is still quite limited number of rain gauge, for example mountainous areas in the norther part and east coast area. This study aims to statistically evaluate two near-real-time satellites-based precipitation products, namely GSMaP_NRT and PERSIANN-CCS during 2009-2013. GSMaP_NRT is hourly product with 0.1 x 0.1 degree and 4-hour latency while PERSIANN-CCS is hourly product with 0.04 x 0.04 degree with 1-hour latency. Compared to the Thai Meteorological Department rain gauge data (TMD), the two satellite-based precipitation products depict the spatial distribution well, with underestimation in monthly and annual rainfall especially in the east coast river basin and the southern parts of Thailand. The daily comparison depicts different trends in each river basin. Further adjustment to reduce bias of the satellite-based precipitation should be implemented.**

Keywords—satellite-based precipitation, GSMaP_NRT, PERSIANN-CCS

I. INTRODUCTION

Rainfall is a primary data for hydrological simulations and assessment of water-related disasters [10 ,11]. However, there is still quite limited number of rain gauge, especially in mountainous area.

Thailand, located in Southeast Asia, has experienced frequent floods and droughts. Rainfall in Thailand is influenced by monsoons and tropical storms. There is a good network of rain gauge covering all over the country by several agencies including Thai Meteorological Department (TMD), Royal Irrigation Department (RID), Department of Water Resources (DWR), and Hydro and Argo Informatics Institute (HAII). However, in some area such as the northern part and east coast area of Thailand, they are mountainous regions which make it difficult to install and maintain rain gauge. Satellite-based precipitation products are publicly available and provide continuous series of high temporal and spatial resolution data especially for regions with limited rain gauge. However, satellite-based precipitation is derived from microwave, near infrared and radar signals thus they normally contain bias. Furthermore, the satellite-based rainfall products have bias due to the estimation algorithm [4]. These products need the rain gauge data for improving the bias by bias correction [5].

This study aims to evaluate the precipitation data from two near real time satellite-based products namely, Global Satellite Mapping of Precipitation – Near Real Time (GSMaP_NRT) [8] and Remotely Sensed Information using Artificial Neural-Network – Cloud Classification System (PERSIANN-CCS) [6][9] over Thailand. The two near real time satellite-based rainfall products are compared with the observed rainfalls from TMD by analyzing statistics such as root mean squared error (RMSE), Pearson correlation coefficient (r), bias of estimation, hit rate (HR) and false alarm rate (FAR) [7, 10].

II. DATA

A. Thai Meteorological Department (TMD) precipitation

The observed rainfall used in this study is from the 124 rain gauges of Thai Meteorological Department (TMD) as shown in Fig. 1. The rain gauge is manual, and the rainfall data are collected every three hours. The rainfall data used are from 2009-2013

B. Global Rainfall Map in Near-Real-Time (GSMaP_NRT)

GSMaP_NRT is a satellite-based rainfall product and the data are available from https://sharaku.eorc.jaxa.jp/GSMaP/ with latency time of four hours. This system uses the remote sensing data from microwave and infrared. GSMaP_NRT developed by TRMM Precipitation Radar (PR) which used to collect the data. GSMaP_NRT covers from 60 degrees Northern to 60 degrees Southern, and the time zone reference is Coordinated Universal Time (UTC) to indicate time of data by HIMAWARI satellite. The temporal resolution is 1 hour, and the spatial resolution is 0.1 degree. [3]

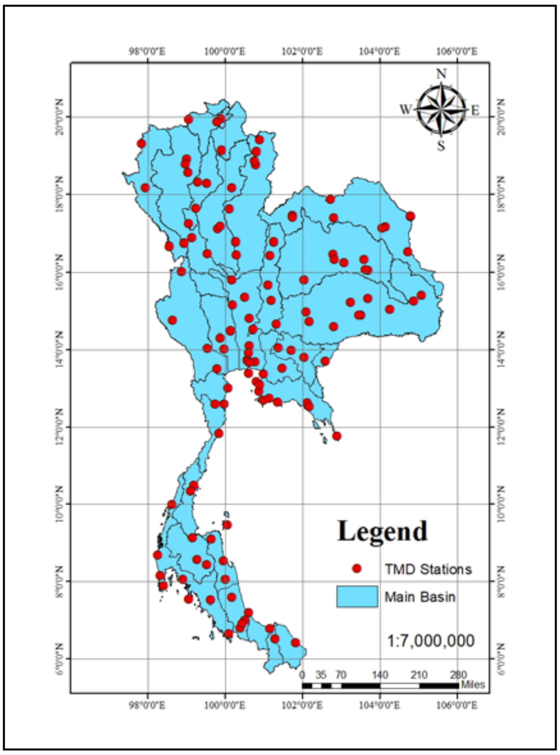


Fig. 1. Map of Thai Meteorological Department's 124 rain gauges in Thailand

C. *Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks Cloud Classification System (PERSIANN-CCS)*

PERSIANN-CCS covers from 60 degrees Northern to 60 degrees Southern. The temporal resolution is 1 hour, and the spatial resolution is 0.04 degree. [2] PERSIANN-CCS uses the cluster technique to classify the type of cloud by using image processing from satellite geo-station infrared. The rainfall data can be downloaded from http://chrsdata.eng.uci.edu/

III. METHODOLOGY

The performance of satellite-based rainfall is evaluated in this study by two aspects. The first aspect is the estimated rainfall amount, the correlation, the bias of estimation between the satellite-based rainfall and the observed rainfall. The second aspect investigated is the potential of the satellite-based rainfall in detecting the rain and bias of detection using the contingency table.

A. *Exploratory Indices*

The estimated near real time rainfall from GSMaP_NRT and PERSIANN-CCS were compared with the observed rainfall from TMD by calculating the RMSE and correlation coefficient. The equation to calculate the root mean squared error (RMSE) is shown in equation (1). RMSE measures the averaged difference between rainfall estimated by a satellite-based precipitation product (X_{sat}) and the rainfall observed by a rain-gauge data from TMD (X_{obs}). [1]

$$RMSE = \sqrt{\frac{\sum (X_{obs}-X_{sat})^2}{N}} \qquad (1)$$

Where N is a number of total data

The Pearson correlation coefficient (r) indicates the strength and direction of a linear relationship between two variables, which are the satellite based-rainfall data and observed data in this study as shown in equation (2). The Pearson correlation coefficient is +1 in the case of a perfect increasing linear relationship, and -1 in case of a decreasing linear relationship. When the correlation coefficient is equal to 0, it means there is no linear relationship between two variables.

$$r = \frac{\sum (X_{obs}-\overline{X_{obs}})(X_{sat}-\overline{X_{sat}})}{\sqrt{\sum (X_{obs}-\overline{X_{obs}})^2 \sum (X_{sat}-\overline{X_{sat}})^2}} \qquad (2)$$

Bias of estimation is an averaged difference between the observation data and satellite-based rainfall data. The bias of estimation is calculated as shown in equation (3). When the bias of estimation less than zero, it means the satellite data overestimate the observed data, and when the bias is more than zero, it means the satellite data underestimate the observed rainfall.

$$Bias\ of\ estimation = \frac{1}{N}\sum (X_{obs} - X_{sat}) \qquad (3)$$

B. *Contingency Table*

The contingency table as shown in Fig. 2 displays the relationship of rainfall detection between rain gauge and satellite-based algorithm. [1]

		Observation		
		Yes	No	
Satellite	Yes	a	b	a+b
	No	c	d	c+d
		a+c	b+d	n = a+b+c+d

Fig. 2. Relationship between counts (letters a – d) of satellite-based data pairs for the dichotomous nonprobability verification situation as displayed in a 2x2 contingency table.

Hit (a) is a number of days that both rain gauge and satellite data report rainfall, , false alarm (b) is a number of days that rain gauge do not report rainfall but satellite data do, miss (c) is a number of days that rain gauge reports rainfall but satellite data do not, and correct negative (d) is a number of days that both rain gauge and satellite data do not report rainfall.

Hit rate (HR) is a proportion of hit to a number of days that rain gauge reports rainfall (a and c) as shown in equation (4).

This index indicates the accuracy of satellite data in detecting rainfall.

$$HR = \frac{a}{a+c} \quad (4)$$

False alarm rate (FR) is a proportion of false alarm (b) to a number of days that rain gauge does not report rainfall (b and d) as shown in equation (5).

$$FR = \frac{b}{b+d} \quad (5)$$

IV. Results & Discussion

The scatter plots of daily, monthly, and annual rainfall over Thailand comparing between rain gauge and the two near-real-time satellites-based rainfall products, GSMaP_NRT and PERSIANN-CCS, are shown in Fig. 3, 4, and 5, respectively. The statistical indices are summarized in Table I. For daily rainfall, the correlation coefficients of GSMaP_NRT and PERSIANN-CCS are 0.46 and 0.43, respectively. The satellite-based rainfall both underestimates and overestimates rain gauge measurement on the daily time scale. The bias of GSMaP_NRT is 0.74 while that of PERSIANN-CCS is -0.15 mm/day. The RMSE of GSMaP_NRT is 12.6 mm/day which is lower than that of PERSIANN-CCS.

For monthly time scale, the correlation coefficient is much improved compare to the daily data. This is because the satellite-based rainfall products both under and overestimate resulting in less errors when summing to the monthly time scale. The correlation coefficients of GSMaP_NRT and PERSIANN-CCS are 0.75 and 0.66, respectively. The bias of GSMaP_NRT is positive indicating underestimation while the bias of PERSIANN-CCS is negative indicating overestimation. The RMSE of GSMaP_NRT is lower than PERSIANN-CCS.

For annual time scale, the correlation coefficient is lower than the monthly scale for PERSIANN-CCS. For the annual rainfall greater than 1000 mm, both satellite-based rainfall products underestimate rain gauge measurement. The bias of GSMaP_NRT is positive indicating underestimation while PERSIANN-CCS is overestimating. The RMSE of annual rainfall of GSMaP_NRT is lower than PERSIANN-CCS.

TABLE I. SUMMARY OF EXPLORATORY INDICES

	GSMaP_NRT			PERSIANN-CCS		
	R	**RMSE**	**Bias**	**R**	**RMSE**	**Bias**
Daily	0.46	0.74 mm./d.	12.63 mm./d.	0.43	-0.15 mm./d.	13.04 mm./d.
Monthly	0.75	18.40 mm./m.	105.82 mm./m	0.66	-8.63 mm./m.	125.86 mm./m.
Annual	0.74	225.78 mm./y.	556.27 mm./y.	0.45	-99.13 mm./y.	680.30 mm./y.

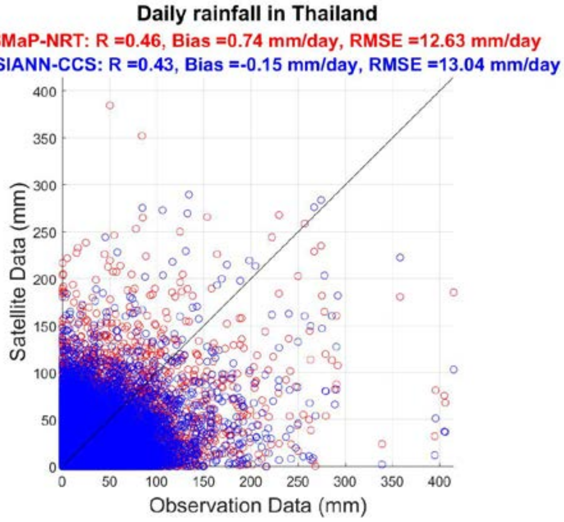


Fig. 3. Scatter plot of daily rainfall over Thailand.

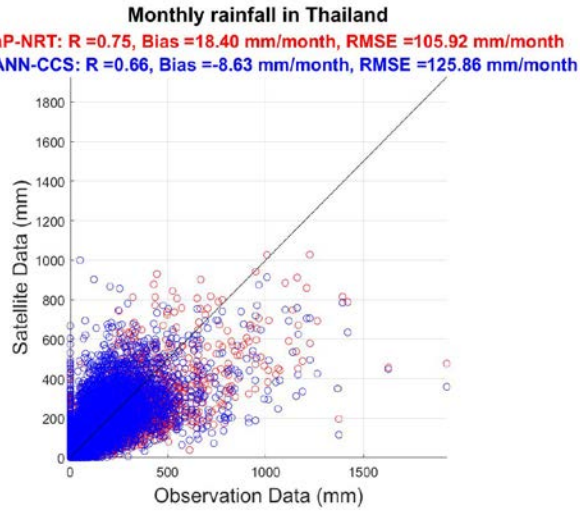


Fig. 4. Scatter plot of monthly rainfall over Thailand.

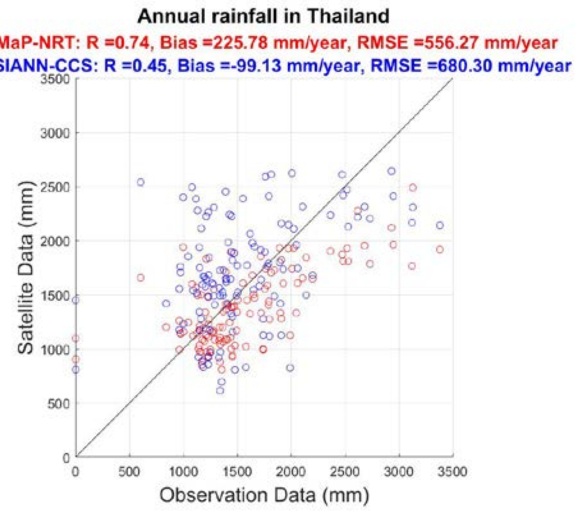
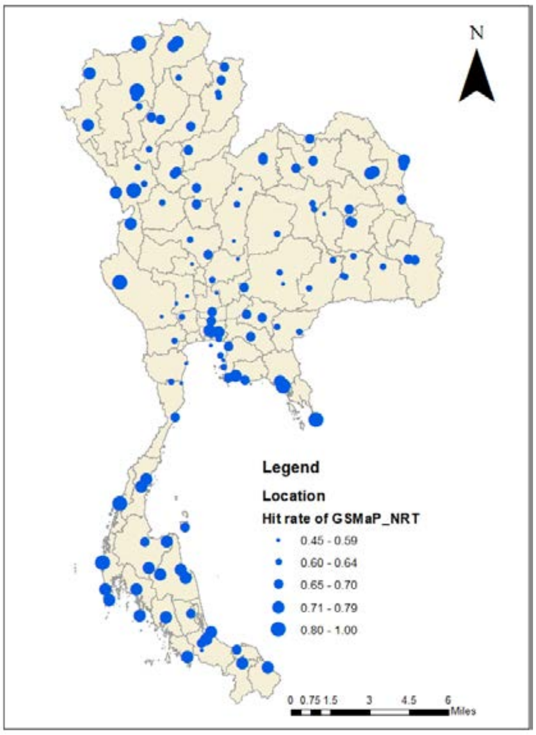
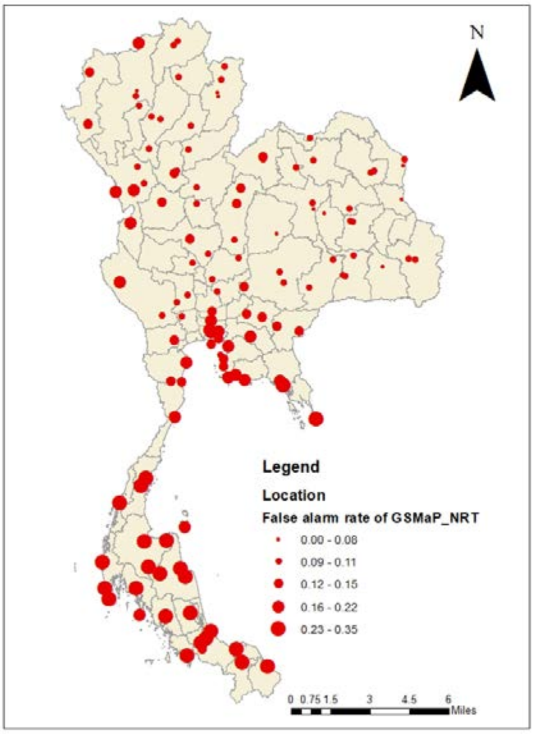


Fig. 5. Scatter plot of annual rainfall over Thailand.

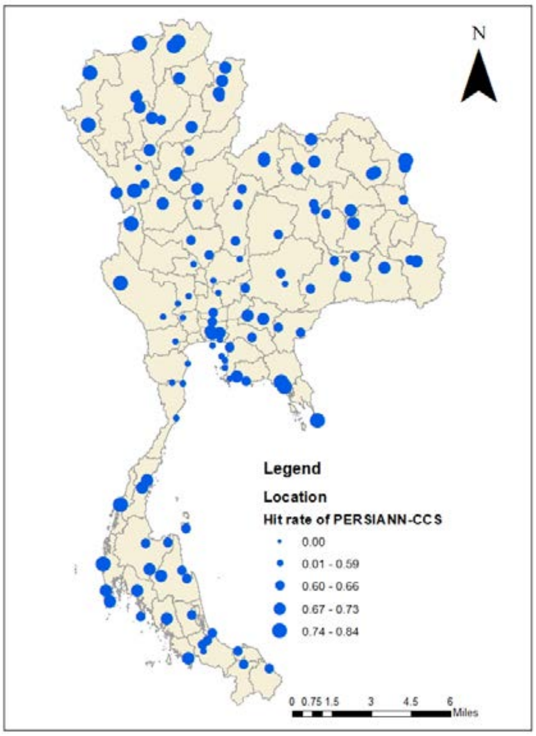


(a) Hit rate of GSMaP_NRT over Thailand

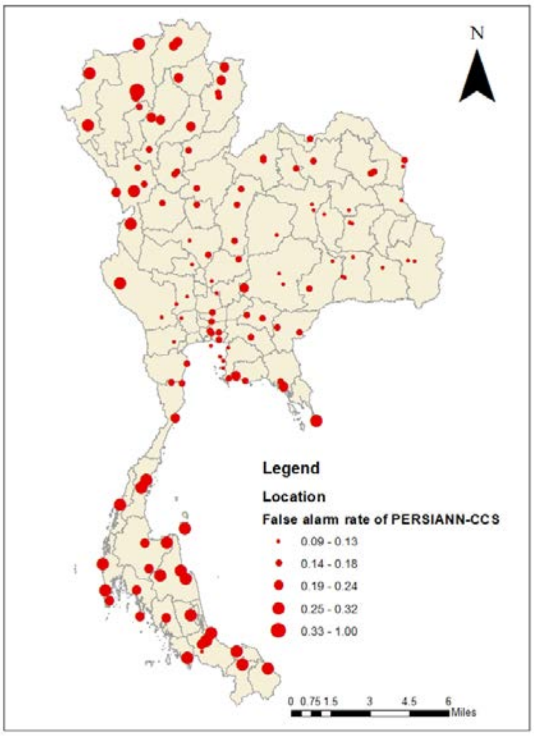


(b) False alarm rate of GSMaP_NRT over Thailand.

Fig. 6. Hit rate and false alarm rate of GSMaP_NRT over Thailand.



(a) Hit rate of PERSIANN-CCS over Thailand



(b) False alarm rate of PERSIANN-CCS over Thailand.

Fig. 7. Hit rate and false alarm rate of PERSIANN-CCS over Thailand.

Fig 6 (a) and (b) shows the hit rate and false alarm rate of GSMaP_NRT of grids that are corresponding with the TMD rain gauges. Similarly, Fig 7 (a) and (b) shows the hit rate and false alarm rate of PERSIANN-CCS. The maps show the non-uniform distribution of the hit rate and false alarm rate over Thailand. The hit rate in the central part is relatively low. The false alarm rate of GSMaP_NRT in the eastern and southern parts are high. For PERSIANN-CCS, the false alarm rate is high in the norther and southern parts. The results show that the performance of satellite-based rainfall products depends on area. The overall hit rate and false alarm rate is shown in Table II. The hit rate and false alarm rate are very close between the two products and they show a good potential in using the near-real-time satellite-based rainfall together with rain gauge measurement in hydrologic forecasting and simulations.

TABLE II. THE AVERAGE HIT RATE AND FALSE ALARM RATE OF SATELLITE-BASED RAINFALL PRODUCTS.

	HR	FR
GSMaP_NRT	0.65	0.18
PERSIANN-CCS	0.67	0.15

V. CONCLUSION

Satellite-based precipitation products are publicly available and provide continuous series of high temporal and spatial resolution data especially for regions with limited rain gauge. It can be used complimentarily with rain gauge in the assessment of water-related disasters. In this study, two near-real-time satellites-based precipitation products, namely, GSMaP_NRT and PERSIANN-CCS during 2009-2013 are evaluated. GSMaP_NRT is hourly product with 0.1 x 0.1 degree and 4-hour latency while PERSIANN-CCS is hourly product with 0.04 x 0.04 degree with 1-hour latency. The satellite-based rainfalls are compared with daily rainfall from TMD rain gauge over Thailand.

The results show a good potential of the two satellite-based rainfall products with the hit rate of 65-67% and the false alarm rate of 15-18%. For the overall performance, GSMaP_NRT is relatively better than PERSIANN-CCS. Comparison at the daily time scale showing the correlation coefficient of 0.43-0.46 while the correlation coefficients of the monthly and annual time scales increase to 0.45-0.75. This is a result from the under and overestimation on the daily time scale. For annual rainfall greater than 1000 mm, both satellite-based rainfall products underestimate the rain gauge. It should be noted that the performance of the satellite-based rainfall products significantly varies spatially. Further adjustment to reduce bias of the satellite-based precipitation should be implemented.

ACKNOWLEDGMENT

The authors would like to express their gratitude to the Thai Meteorological Department for the observed rainfall data, JAXA and NASA for GSMaP_NRT, the CHRS center at University of California Irvine for PERSIANN-CCS. We acknowledge the partial funding from Department of Water Resources Engineering, Faculty of Engineering, Chulalongkorn University and Hydro and Agro Informatics Institute (HAII).

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