Article

Evaluation of GSMaP Precipitation Estimates Over Indonesia

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Received: 14 May 2018; Accepted: 28 May 2019; Available online: 1 June 2019

Abstract

Generally, observation of the rainfall in Indonesia are still conventionally using rain gauge over Indonesian region. The rain gauge network are still the most reliable source over Indonesia, however this network is not as dense as in the other major continents. The aim of this research were validation and evaluate the annual rainfall periodicity and to obtain the correction factor of the GSMaP rainfall estimation data in Indonesia. Data used in this research are daily rainfall derived from GSMaP_MVK Ver.5 and in-situ data from rain gauge measurement by BMKG from March 2000 to November 2010. The validation showed that the satellite estimate gave an underestimated condition in all of three dominant rainfall characteristics region in Indonesia. The pattern of monthly rainfall time series average based on 40 stations from March 2000 – November 2010 showed quite similar than rain gauge pattern. The relationships of monthly rainfall average showed very good agreement with rain gauge data giving very high correlation (r=0.82 – 0.92) MBE and RMSE was less than 100 mm/month. The result of spectral analysis using DFT also showed a good agreement with rain gauge spectral analysis data on monthly.

Keywords: *rainfall; GSMaP; rain gauge; validation; DFT*

1. Introduction

The Indonesian archipelago is characterized as a huge amount rainfall throughout the year, and plays the essential role as a center of atmospheric heat source of earth climate system (Ramage, 1971). The information about rainfall characteristic in Indonesia is very important to study climatology, oceanography, and water resources of the global system. Generally, observation of the rainfall in Indonesia are still conventionally using rain gauge over Indonesian archipelago. The Global Satellite Mapping of Precipitation (GSMaP) Project started in November 2002. The aim of the GSMaP Project is develop an advanced microwave radiometer algorithm based on the deterministic rain-retrieval algorithm that produce a precise high-resolution global precipitation maps. In this project, the algorithms are developed based on physical models of precipitation including melting layers and particle-size distribution. The GSMaP Project has also been developing algorithms combined with the passive microwave and Geostationary Earth Orbit (GEO) infrared (IR) radiometers. This project provide a global mapping of precipitation that have the temporal resolution of 1 hour and the spatial resolution of 0.1 x 0.1 degree (Kubota et al. 2007). Aldrian and Susanto (2003) said that rainfall patern in Indonesia divide into three regions, region A or monsoon that monthly rainfall distribution associated with Asia monsoon and characterized by unimodial type. Region B or semi monsoon that monthly rainfall distribution associated with the southward and northward movement of the inter-tropical convergence zone (ITCZ), characterized by bimodial type and Region C or anti monsoon that monthly rainfall distribution associated with the local condition in Maluku waters and has one peak of rainy season that opposite of monsoonal type. This regionalization is still be the refference of some research about rainfall pattern in Indonesia until now, because the most completeness and the longest time range of the rainfall data over Indonesian region.

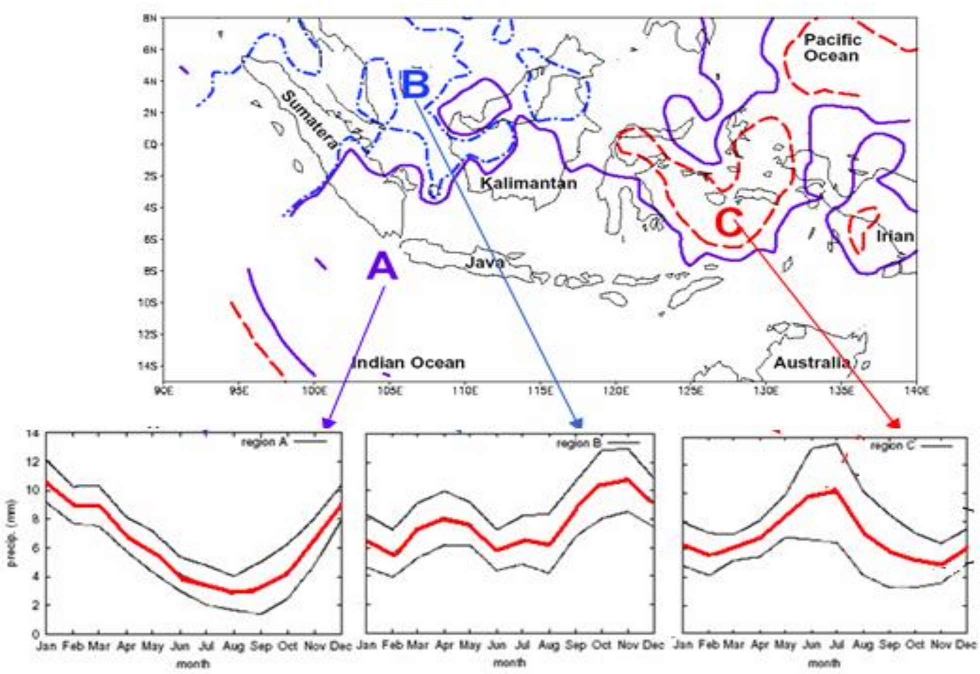


Figure 1. Rainfall patterns in Indonesia (Aldrian and Susanto, 2003)

This study investigates the accuracy of GSMaP rainfall estimation data that is validated by rain gauge data over Indonesian region and the annual periodicity of rainy season peak in Indonesian region based on GSMaP rainfall estimation data and to obtain the correction factor of the GSMaP rainfall estimation data in Indonesian region.

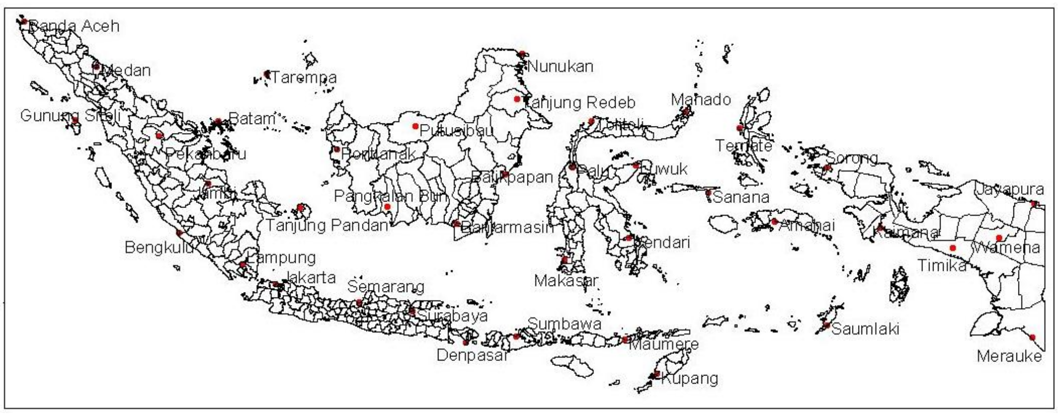


Figure 2. Study Area Ana ain gauges location (red dots)

2. Study Area

Indonesian archipelago is located in 92.50^0 E – 141.20^0 E and 8.14^0 N – 12.0^0 S. Distribution of research locations are 40 rain gauge stations according to the three dominant rainfall patterns by Aldrian and Susanto (2003), 20 stations located in parts of Indonesia which covers the monsoonal type (A) area : Jambi, Bengkulu, Lampung, Jakarta, Semarang, Surabaya, Pangkalan Bun, Banjarmasin, Balikpapan, Makassar, Kendari, Denpasar, Sumbawa, Maumere, Kupang, Saumlaki, Manado, Jayapura, Kaimana, and Merauke, 11 stations located in Semi monsoonal type (B) area : Banda Aceh, Medan, Gunung Sitoli, Pekanbaru, Tarempa, Batam, Tanjung Pandan, Pontianak, Putussibau, Nunukan, and Tanjung Redeb, 6 stations located in anti monsoonal (C) type area : Amahai, Sanana, Luwuk, Tolitoli, Sorong, Timika and 3 stations located in intermediate area : Palu, Ternate, Wamena as shown in Figure 2.

3. Data and methods

3.1 Data in this research as follows:

- Daily rainfall data derived from GSMaP_MVK Ver.5 from March 2000 – November 2010 (downloaded from ftp://hokusai.eorc.jaxa.jp/standard/v5/txt) at Asia SE and Australia region.
- Daily rainfall in situ data derived from Rain Gauge Measurement Station from March 2000 – November 2010 (Indonesian Meteorology Climatology and Geophysic Agency – BMKG).

3.2 Validation methods

3.2.1. Continuous statistic method

Statistical routines could be use to analyze the relationship of the GSMaP data to rain gauge data on daily and monthly. The measure of the closeness of the GSMaP data to the observed data will be the linear correlation (r), the mean bias error (MBE) and the root mean square error (RMSE) defined as follows (Feidas, 2010) :

- Coefficient of Correlation (r):

This analysis is performed to determine the relationship between daily and monthly rainfall data from GSMaP and rain gauge data. With the correlation analysis can identify how the validity of GSMaP rainfall data.

$$r = \frac{\sum_{i=1}^{n}\left(S_i - S\right)\left(G - \bar{G}\right)}{\sqrt{\sum_{i=1}^{n}\left(S_i - \bar{S}\right)^2}\sqrt{\sum_{i=1}^{n}\left(G - \bar{G}\right)^2}} \quad (1)$$

- Mean Bias Error (MBE)

MBE is good measure of model bias and is simply the average of all differences in the set. This provides a measure of general MBE, but not of average error that could be expected.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}\left(S_i - G_i\right) \quad (2)$$

- Root Mean Square Error (RMSE)

This analysis is used to find out how much the average error value between data from GSMaP and rain gauge. The equation is:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(S_i - G_i\right)^2} \quad (3)$$

Where Si are the GSMaP data values, Gi are the refference gauge values and n are the numbert of data pairs.

3.2.2. Categorical statistic method

As shown in Table 1 above, the "hits" represents correctly estimated rain events, "misses" describes when rain is not estimated but actual rain occurs, "false alarm" represents when rain is estimated but actual rain doesn't occur, and "correct negative" represents correctly estimated no-rain events. Using the results shown in Table 1, the parameters POD and FAR are calculated by following Equations 4 and 5.

Table 1. Contingency table of yes or no events with rain or no rain

	Estimated rainfall	
Rainfall	Yes	No
Yes	Hits	Misses
No	false alarm	correct negative

$$POD = \frac{hits}{hits + misses} \tag{4}$$

$$FAR = \frac{false\,alarm}{hits + false\,alarm} \tag{5}$$

3.2.3. Spectral Analysis Method

The Discrete Fourier Transform (DFT) is the equivalent of the Continuous Fourier Transform for signals known only at instants separated by sample times (i.e. a finite sequence of data). The basic equation of Fourier Transform showed in equation 6, with transform the continuous time signal or infinite signal. While the equation 7, 8, and 9 spell out the Fourier Transform which transform a discrete signal or called Discrete Fourier Transform. The discrete signal or discrete- time signal is a time series, perhaps a signal that has been sampled from a continuous- time signal. If f(t) be a continuous signal, then the Fourier Transform of the signal is (Allen et al., 2009) :

$$f(j\omega) = \int_{-\infty}^{\infty} f(t) e^{j\omega t} dt \tag{6}$$

Where N samples be denoted f[0] = f[1], f[2], f[3],.... f[k],..., f[N-1] then

$$F(j\omega) = \int_{0}^{(N-1)T} f(t) e^{j\omega t} dt \tag{7}$$

$$= f[0]e^{-j0} + f[1]e^{-j\omega t} + ... + f[k]e^{-j\omega t} + ... f[N-1]e^{-j\omega(N-1)T} \tag{8}$$

$$= \sum_{k=0}^{N-1} f[k] e^{-j\omega kt}, \quad k = 0,1,2,...,N-1 \tag{9}$$

3.2.4. Least Square Method

The Method of Least Squares is a procedure to determine the best fit line to data uses simple calculus and linear algebra. A line of best fit is a straight line that is the best approximation of the given set of data. It is used to study the nature of the relation between two variables. A line of best fit can be roughly determined using an eyeball method by drawing a straight line on a scatter plot so that the number of points above the line and below the line is about equal and the line passes through as many points as possible. A more accurate way of finding the line of best fit is the least square method. The following steps to find the equation y=mx+c of best fit line for a set of ordered pairs $(x_1,y_1),(x_2,y_2),\ldots,(x_n,y_n)$ are (Brown, 2001):

$$\bar{X} = \frac{\sum_{i=1}^{n} x_i}{n} \tag{10}$$

$$\bar{Y} = \frac{\sum_{i=1}^{n} y_i}{n} \tag{11}$$

$$m = \frac{\sum_{i=1}^{n}\left(x_i - \bar{X}\right)\left(y_i - \bar{Y}\right)}{\sum_{i=1}^{n}\left(x_i - \bar{X}\right)^2} \tag{12}$$

$$c = \bar{Y} - m\bar{X} \tag{13}$$

4. Result and discussion

Daily rainfall relationships based on 20 locations in region A showed 6 point gauges in very low correlation (r=0.04 – 0.19), 6 points gauges in low correlation (r=0.23 – 0.38) and 8 points gauges in medium correlation (r=0.44 – 0.49). RMSE are more than 10 mm/day except in Maumere (8.64 mm/day) and MBE showed less than 7 mm/day where 17 points were underestimate and 3 points were overestimate. The categorical statistics showed POD was 0.68 average where maximum 0.87 in Pangkalan Bun and minimum 0.29 in Denpasar. While FAR showed 0.36 average where maximum 0.49 in Lampung and Jakarta, and minimum 0.23 in Manado. It means that 68% of rain occurrences were correctly detected and 36% of rain occurrences turned out to be wrong by GSMaP. These values of two categorical statistics showed that GSMaP product was reasonably good at detecting the precipitation events over Region A. Moving average of monthly rainfall measured by GSMaP and rain gauge in region A shown in Figure 3a. The monthly rainfall from GSMaP was very slightly than monthly gauge data, where the average of monthly rainfall from GSMaP were 148.12 (mm/month) with 84.55 of standard deviation, meanwhile the average of monthly rainfall from rain gauge were 198.71 (mm/month) with 114.60 of standard deviation. The monthly average relationships between GSMaP and rain gauge was very high correlation (r=0.92), RMSE was 70 mm/month, and MBE was -50.59.

Daily relationships based on 11 locations in Region B showed 3 point gauges in very low correlation (r=0.03 – 0.16), 2 point gauges in low correlation (r=0.24 – 0.34) and 6 point gauges in medium correlation (r=0.45 – 0.48). RMSE were more than 10 mm/day and MBE showed less than 3 mm/day where 8 points were underestimate and 3 points were overestimate. The categorical statistics showed POD was 0.78 average where maximum 0.92 in Pontianak and minimum 0.29 in Tarempa. While FAR showed 0.33 average where maximum 0.53 in Banda Aceh, and minimum 0.21 in Tanjung Pandan. It means that 78% average of rain occurrences were correctly detected and 33% average of rain occurrences turned out to be wrong by GSMaP. These values of two categorical statistics showed that GSMaP product was reasonably good at detecting the precipitation events over Region B. Time series moving average of monthly rainfall in Region B was shown in Figure 3b. The monthly rainfall from GSMaP was also very slightly than monthly gauge data, where the monthly rainfall average from GSMaP were 201.8 (mm/month) with 62.09 of standard deviation, meanwhile the average of monthly rainfall from rain gauge were 224.71 (mm/month) with 67.24 of standard deviation. The pattern of GSMaP monthly rainfall average showed quite similar with gauge data. The monthly average relationships between GSMaP and rain gauge was very high correlation (r=0.82), RMSE was 44.6 mm/month, MBE was -22.9.

Daily relationships based on 6 locations in region C showed 3 point gauges in very low correlation (r=0.06 – 0.19), 2 point gauges in low correlation (r=0.36 – 0.38) and 1 point gauges in medium correlation (r=0.40). RMSE were more than 10 mm/day and MBE showed less than 4 mm/day where 5 points were underestimate and 1 points were overestimate. The categorical statistics showed POD was 0.70 average where maximum

0.87 in Timika and minimum 0.51 in Sanana. While FAR showed 0.39 average where maximum 0.52 in Luwuk, and minimum 0.23 in Timika. Moving average of monthly rainfall measured by GSMaP and rain gauge based on 6 points in Region C was shown in Figure 3c. The monthly rainfall average from GSMaP was adequately similar than monthly gauge data, where the average of monthly rainfall from GSMaP were 201.8 (mm/month) with 64.58 of standard deviation, meanwhile the average of monthly rainfall from rain gauge were 224.71 (mm/month) with 98.07 of standard deviation. The pattern of GSMaP average time series monthly rainfall showed quite similar with gauge data. The monthly average relationships between GSMaP and rain gauge was very high correlation (r=0.82), RMSE was 44.6 mm/month, MBE was -22.9.

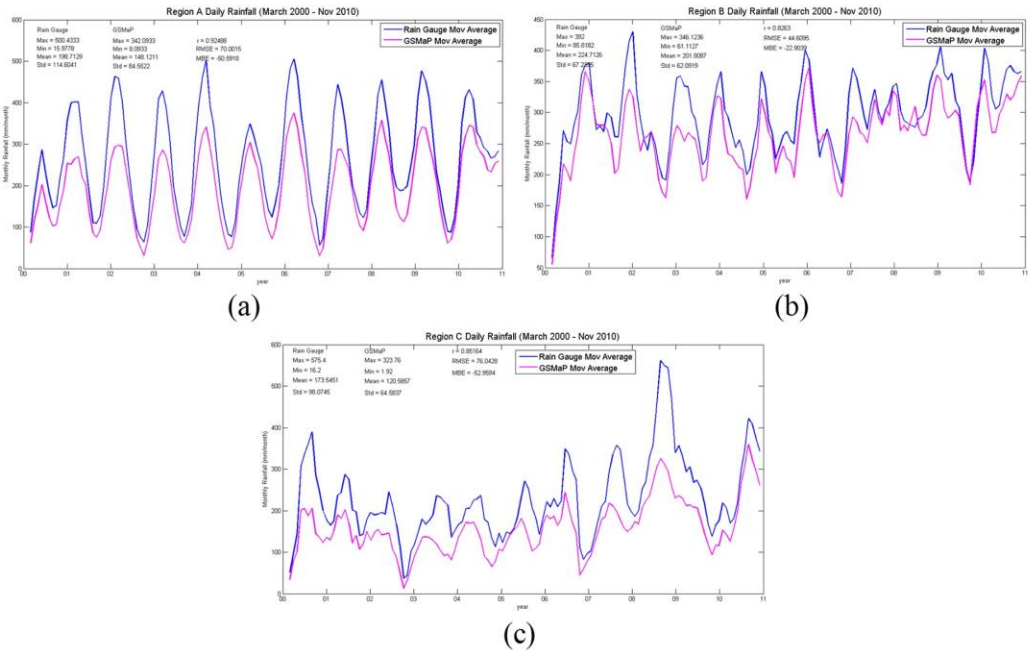


Figure 3. Time series moving average of monthly rainfall measured by GSMaP and rain gauge in (a) Region A, (b) Region B, and (c) Region C

Scatterplot of monthly rainfall average between GSMaP and rain gauge data based on 20 locations in Region A shown in Figure 4a that showed a strong relationships to obtain the best fit line that is the best approximation to be a correction factor of GSMaP monthly rainfall average data in Region A using least square method that is $y = 1.2536\,x + 13.0279$ with y=actual rainfall, x=GSMaP data and the coefficient determination was $r^2 = 0.8554$. Meanwhile, scatterplot of monthly rainfall average between GSMaP and rain gauge data based on 11 locations in Region B shown in Figure 4b that also showed strong relationships to obtain the best fit line that is the best approximation to be a correction factor of GSMaP monthly rainfall average data in Region B using least square method that is $y = 0.8948x + 44.1326$, and the coefficient determination was $r^2 = 0.6828$. Futhermore, scatterplot of monthly rainfall average between GSMaP and rain gauge data based on 6 locations in Region C shown in Figure 4c that also showed strong relationships to obtain the best fit line that is the best approximation to be a correction factor of GSMaP monthly rainfall average data in region C that is $y = 1.2933x + 17.5956$, and the cooefficient determination in Region C was $r^2 = 0.7253$.

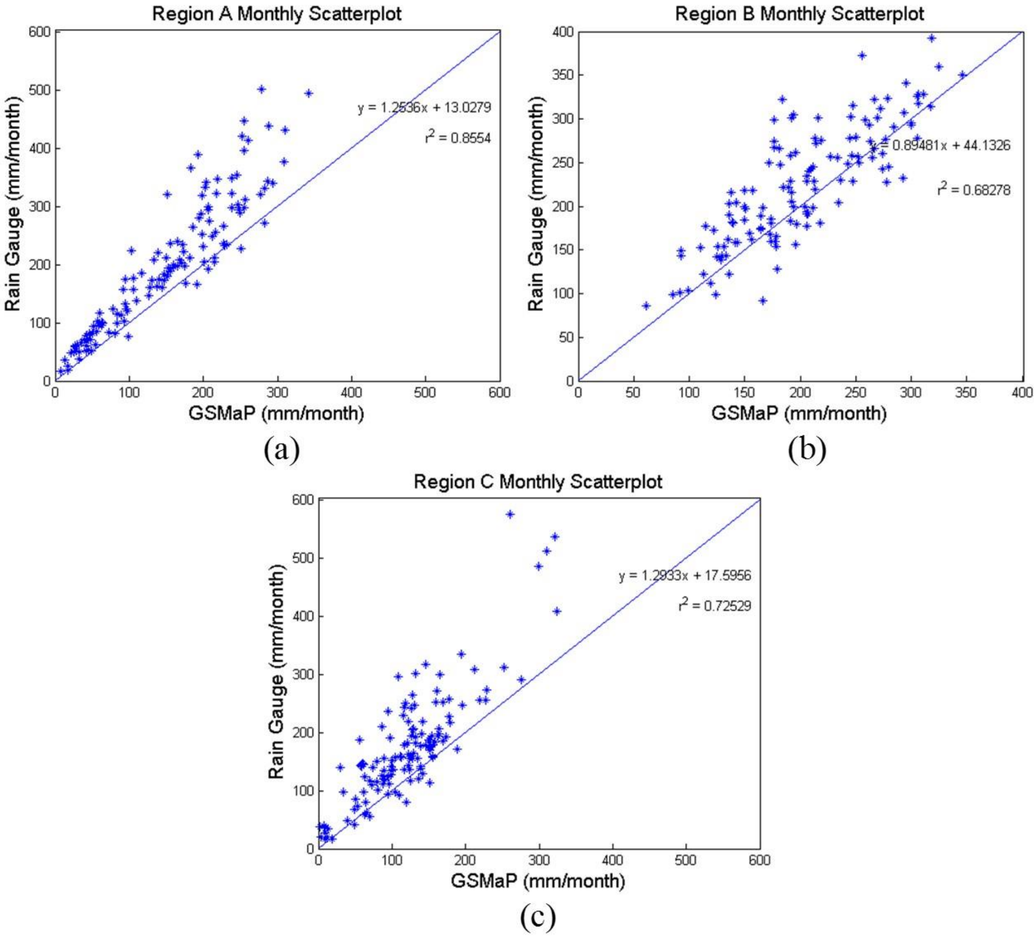


Figure 4. Monthly Scatterplot measured by GSMaP and rain gauge in (a) Region A, (b) Region B, and (c) Region C

Annual rainfall periodicity average based on 20 locations in monsoonal type (A) from March 2000 – November 2010 shown in Figure 5a. The power spectrum showed there was one rainfall peak on 11.64 month/cycle that indicates an annual rainfall peak in monsoonal type. Magnitude of rainfall spectrum power measured by GSMaP was 3.52 x 10^7. Meanwhile the magnitude of rainfall spectrum power measured by rain gauge was 6.33 x 10^7 higher than GSMaP data power spectrum. It indicates the underestimate characteristic of GSMaP data, according to the monthly rainfall graph shown in Figure 3a. Annual periodicity of rainfall average based on 11 locations in semi-monsoonal type (B) shown in Figure 5b. The power spectrum showed there was two rainfall peak on 11.64 month/cycle (annual) and 6.09 month/cycle (semi annual). Magnitude of rainfall spectrum power measured by GSMaP was 4.5 x 10^6 in annual and 5.19 x 10^6 in semi annual. Meanwhile the magnitude of rainfall spectrum power measured by rain gauge was 5.77 x 10^6 in annual and 5.34 x 10^6 in semi annual. Magnitude of semi annual power spectrum detected by GSMaP and rain gauge was so slightly different. GSMaP data showed very good agreement with rain gauge data in semi-annual rainfall periodicity in semi-monsoonal type (B). The magnitude of annual rainfall spectrum power measured by rain gauge higher than GSMaP data of annual power spectrum. It also indicates the underestimate characteristic of GSMaP data in semi-monsoonal type (B), which suitable with the monthly rainfall graph shown in Figure 3b.

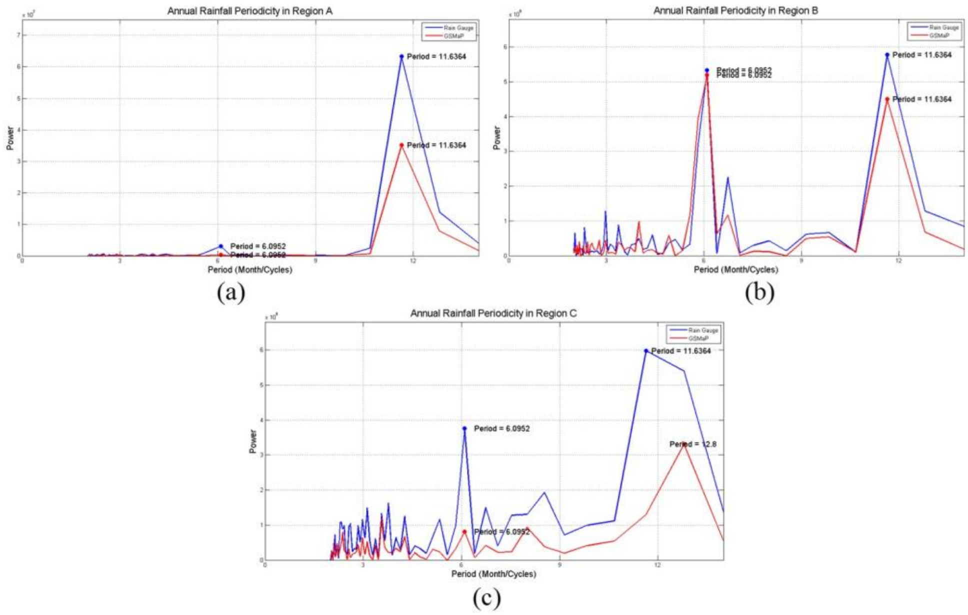


Figure 5. Annual rainfall periodicity measured by GSMaP and rain gauge in (a) Region A, (b) Region B and (c) Region C

Annual periodicity of rainfall average based on 6 locations in anti-monsoonal type (C) shown in Figure 5c. The power spectrum showed there was two rainfall peak. Annual rainfall peak of GSMaP data was 12.8 month/cycle while annual rainfall peak of rain gauge data was 11.64 month/cycle. Semi annual rainfall peak was 6.09 month/cycle both in GSMaP data and rain gauge data. Magnitude of rainfall spectrum power measured by GSMaP was 3.31 x 10^6 in annual and 8.12 x 10^5 in semi annual. Meanwhile the magnitude of rainfall spectrum power measured by rain gauge was 5.98 x 10^6 in annual and 3.76 x 10^6 in semi annual.

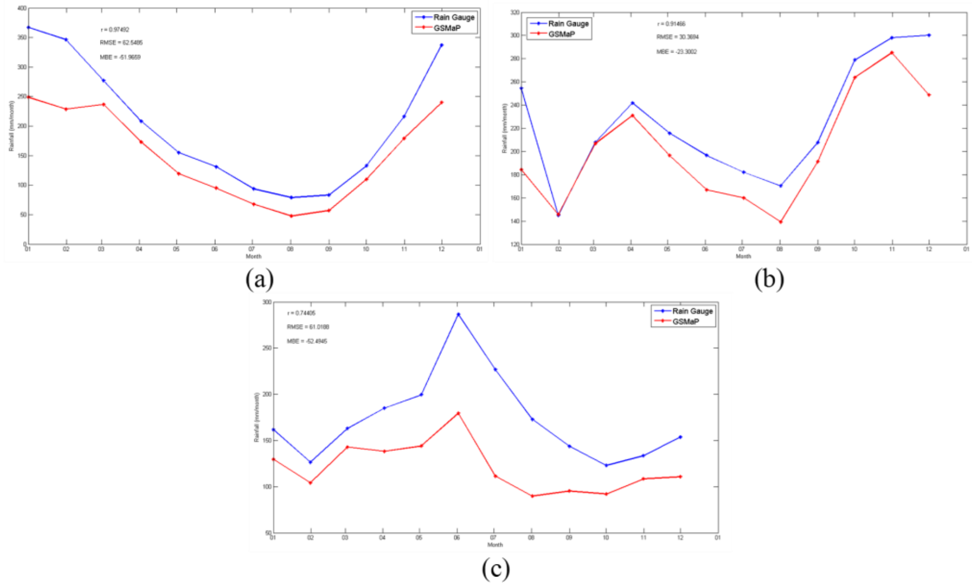


Figure 6. Annual rainfall pattern measured by GSMaP and rain gauge in (a) Region A, (b) Region B and (c) Region C

The results of the spectral analysis using DFT showed that in all of the locations, GSMaP showed good on detecting the power spectrum upper than 1 x 10^7, but not good to detecting the power spectrum lower than 1 x 10^7, except at a very dominant 365.11 days cycle period and also not good at cycle period less than 90 days. So in the locations that have power spectrum under 1 x 10^7 and short period of cycle less than 90 days, GSMaP can not detecting rainfall pattern properly except at the 365.11 days cycle period that very dominant than the others. The spectrum power magnitude limit can be detected as a rainfall peak was 1 x 10^7, except in the locations that all of the power spectrum were under 1 x 10^7. Monthly rainfall average pattern measured by GSMaP and rain gauge in Region A, B, and C was shown in Figure 6a, b, and c. GSMaP data showed very good agreement with the ground reference. The pattern of GSMaP monthly rainfall average showed quite similar with gauge data as ground refference.

The correction factor of GSMaP data obtained from the equation of best fit line using least square method between the average monthly GSMaP data after regionalization and average monthly rain gauge data as refference. The correction factor then will be used to correct the GSMaP rainfall estimate data. This correction factor is useful to correct value when the GSMaP datas will be used as a main rainfall data choice especially in the location that there are no rain gauge in an isolated area. The correction factor obtained from this result showed in Table 2 below where the relationships is very strong between GSMaP data average after regionalization and rain gauge data average in all of the rainfall characteristic region in Indonesia (type A,B, and C). Meanwhile the RMSE and MBE showed good where under 100 mm/month. MBE were negative in all of region that indicated underestimate characteristics in all of the region.

Table 2. Continuous Statistic of Average Monthly Rainfall in All Region

No	Region	R	RMSE (mm/month)	MBE (mm/month)	Correction Factor*
1	Monsoonal (A)	0.92	70.00	-50.59	y=1.2536x + 13.0279
2	Semi-monsoonal (B)	0.83	44.61	-22.90	y=0.8948x + 44.1326
3	Anti-monsoonal (C)	0.85	76.04	-52.95	y=1.2933x + 0.7253

*) y=actual rainfall ; x=GSMaP data

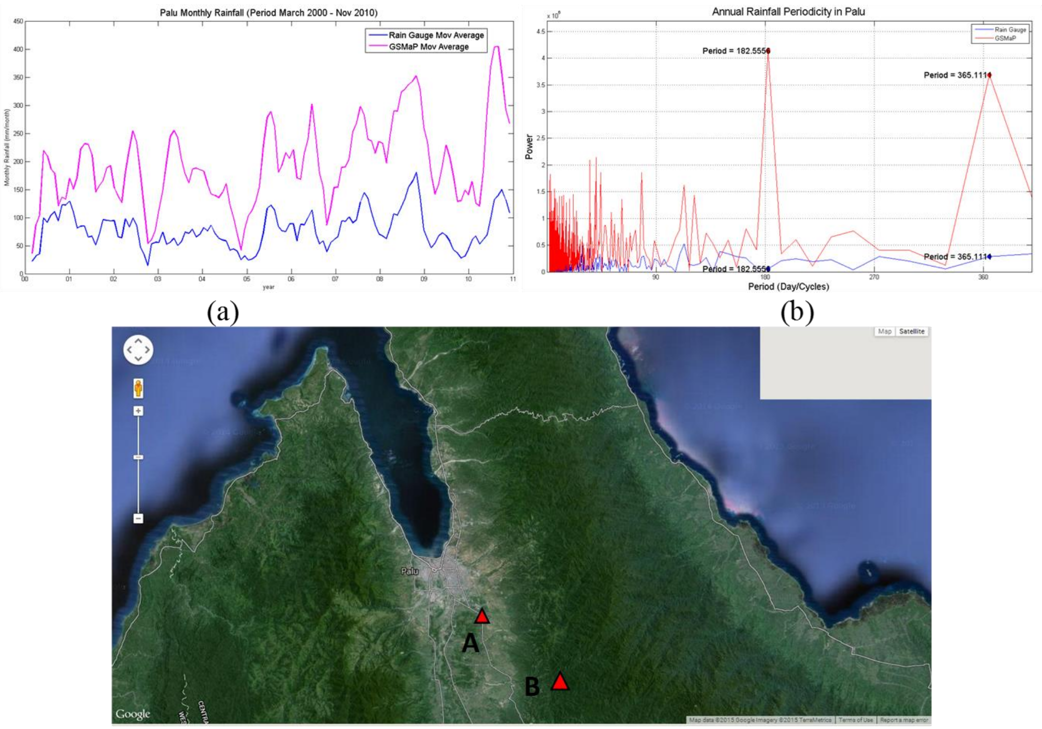
MBE average showed negative value in all region were indicated the underestimate of GSMaP data (Table 2). Neverthelles they are subject to larger biases and stochastics errors and need to be adjusted to in situ observations (Barret et al., 1994; Rudolf et al., 1996). Satellite have biases and random error that are caused by factors such as the sampling frequency, the diurnal cycle of rainfall, the non uniform field of view sensors, and the uncertainties in the rain retrieval algorithms (Bell et al., 1990; Kousky, 1980; Kummerow 1998; Anagnostou et al., 1999; Chiu et al., 1990; Chang and Chiu 1999). Indonesia is a maritime continent region, so the different drop size distribution of rainfall over land and sea may influence statistical error of PR data, especially in anti-monsoonal type rainfall, therefore, there is a special need to study more precise factors of ground rain rates to validate satellite PR data in Indonesia. (Prasetia et al. 2013). Furthermore, limitations of the TRMM data suffer from both a narrow swath and insufficient sampling time intervals, resulting in loss of information about rainfall values and rainfall types (As-syakur, 2013). Meanwhile, the amount of rainfall measured in a rain gauge is less than the actual rainfall reaching the ground. This is mainly due to systematic errors (Huey and Ibrahim, 2012). The systematic errors include losses due to wind, wetting, evaporation, and splashing (Habib et al., 2008). Dinku et al. (2010) investigated the performance of various satellite rainfall products and found that satellite-based estimates did well in detecting the occurrence of rainfall, but were not good in estimating the amount of daily rainfall. Fu et al. (2011) evaluated the accuracy of GSMaP_MVK ver. 4.8.4 using in situ data from 45 rain gauge stations across Poyang Lake Basin in the period between 2003 and 2006 at daily, monthly and annual scales. Their results show that the GSMaP products generally underestimate rainfall amount. The monthly correlation coefficient is 0.85, which shows a significant linear relationship between product estimations and rain-gauged observations while the daily correlation coefficient is less than 0.50 on average. The GSMaP data as the highest temporal and spatial resolution satellite data can detect a precipitation event with the same trend as rain gauge data but the precipitation amount generally has been underestimated (Fukami, 2010; Kubota et al., 2009; Makino, 2012; Seto et al., 2009; Shrestha et al., 2011). In Kumamoto Prefecture, hourly GSMaP_MVK data has a lower correlation coefficient compared with the previous study which validated daily GSMaP_MVK data (Makino, 2012).

Table 3. The stations which MBE upper than -50 mm/month and the distance from the shoreline

No	Station	Rain Gauge		GSMaP		Distance (Km)*			MBE	RMSE
		Lat	Long	Lat	Long	GSMaP – SL***	RG**– SL***	GSMaP – RG**	(mm/ month)	(mm/ Month
1	Batam	1.12	104.12	1.15	104.15	0.87	2.95	4.74	-75.08	161.97
2	Tarempa	3.25	106.25	3.25	106.25	0.91	0.91	0.10	-76.70	126.18
3	Bengkulu	-3.86	102.34	-3.85	102.35	5.16	3.67	1.59	-74.30	146.81
4	Makasar	-5.06	119.55	-5.05	119.55	7.93	7.92	1.12	-114.32	217.42
5	Denpasar	-8.75	115.17	-8.75	115.15	0.24	1.37	2.20	-183.76	278.75
6	Sumbawa	-8.49	117.41	-8.45	117.45	3.83	2.63	6.25	-155.83	248.75
7	Saumlaki	-7.98	131.30	-7.95	131.35	2.17	0.52	6.15	-70.56	112.41
8	Manado	1.55	124.93	1.55	124.95	2.06	0.18	2.22	-163.99	215.82
9	Amahai	-3.35	128.93	-3.35	128.95	0.62	0.27	2.22	-92.10	190.02
10	Sanana	-2.09	125.96	-2.05	125.95	5.72	0.45	5.50	-76.60	127.50
11	Toli Toli	1.12	120.79	1.15	120.75	4.96	0.60	5.57	-92.75	123.07
12	Ternate	0.83	127.38	0.85	127.35	4.42	0.78	3.99	-92.13	123.65
13	Kupang	-10.17	123.67	-10.15	123.65	0.87	3.57	3.13	-50.30	117.48
14	Kendari	-3.96	122.60	-3.95	122.65	2.79	2.87	5.67	-58.78	209.34

*the distance measuring with google map (https://www.google.co.id/maps); **RG = rain gauge; ***SL = shoreline

This research also found that there were strong influence of topographical factors to the mean bias error of the satellite observations. There were high negative mean bias error between monthly rainfall average of GSMaP and rain gauge data in the locations which located close to the shoreline (Table 3), so monthly rainfall of GSMaP in these locations characterized as underestimate. The highest negative MBE showed in Denpasar (MBE=-183.76) where the rain gauge station located between two shoreline which the distances were 780 meters from the east shoreline and 1.37 kilometers from the west shoreline. Table 3 showed 14 stations which had high MBE upper than -50 mm/month which mostly located in monsoonal area and the distance from the shoreline which measure using google map (https://www.google.co.id/maps). It might be that coastal area is the most potential for convective cloud formation in the tropics especially in monsoonal area where the monsoon wind blow from the the high pressure area in the wet season which carries air mass contain much water vapour. In meteorology, convection is a dynamic concept; specifically, it is the rapid, efficient, vigorous overturning of the atmosphere required to neutralize an unstable vertical distribution of moist static energy. Most clouds in the Tropics are convection-generated cumulonimbus (Houze, 1997). The convective region has an updraft and downdraft strong movement which associated with vertical movement of large air that cause the convective rainfall has a very high intensity in a short time period that covers the not so wide area around 30 kilometers square. Sugiartha et al., (2017) said that the GSMaP_MVK shows underestimation of rain gauge data for rainfall intensity greater than 4 mm/h and also miss some small rainfall event, the GSMaP_MVK are generally overestimated to light rainfall and less sensitive to heavy rainfall. Liao and Meneghini (2009), from ground-based radar, they found (particularly in heavy rain) underestimation of PR attenuation for convective rain, while stratiform rain was more accurately corrected. While Prasetia *et al.* (2013) found that except in February and March for semi-monsoonal and anti-monsoonal type rainfall, most precipitation radar monthly rain accumulation was contributed by convective rain events over the period of data collection. Previous studies show convective rainfall predominantly control tropical rainfall peaks (Kubota *et al.,* 2004 ; Mori *et al.*, 2004). These may be because of the intense rain fell that are in gauge proximity are missed by the satellites snapshot and picked by gauges for shorter period (Bangira, 2013). Kubota *et al.* (2009) investigated the performance of six satellite rainfall estimates using passive microwave (PMW) and infrared (IR) radiometers around Japan with reference to a ground-radar dataset calibrated by rain gauges provided by the Japan Meteorological Agency (JMA) from January through December 2004. Overall, validation results over the ocean were best, and results over mountainous regions were worst. Rainfall estimates were poor over coasts and small islands. Underestimation of GSMaP data resulted from no microwave radiometer information during the peak period for heavy rainfall. One reason for the errors was the relatively low POD values due to the rain/no-rain identification problem over coasts. Local effects, such as terrain profile, near to coastal area with sea and land breeze circulations may contribute to the results deviation (Islam *et al.*, 2005). Furthermore, retrieval of precipitation using PMW observations has always represented a problem over coastal areas; often techniques omit retrievals over the coastline, or use a less optimum technique (Kidd and Levizzani, 2011; Kidd and Huffman, 2011; Kelkar, 2007). Comparing 3B43 with rain gauges shows strong agreement, with a high to very high correlation coefficient (r = 0.85–0.98). However, comparison results still showed differences especially when heavy rain occurs. Temporal and spatial sampling uncertainties possibly cause this instability. The Indonesian region is characterized by a high variability in rainfall and strong convective activity. Precipitation events outside these satellite observation windows directly resulted in monthly and seasonal statistical errors (As-syakur, 2013). These underestimate of convective rainfall in the coastal area on the wet season especially in the monsoonal and anti-monsoonal type area were cause the high bias error in this area, also the average of error (RMSE), so although had the higher correlation coefficient, the RMSE and MBE of monsoonal and anti-monsoonal type were also high rather than in semi-monsoonal type area (Table 2).

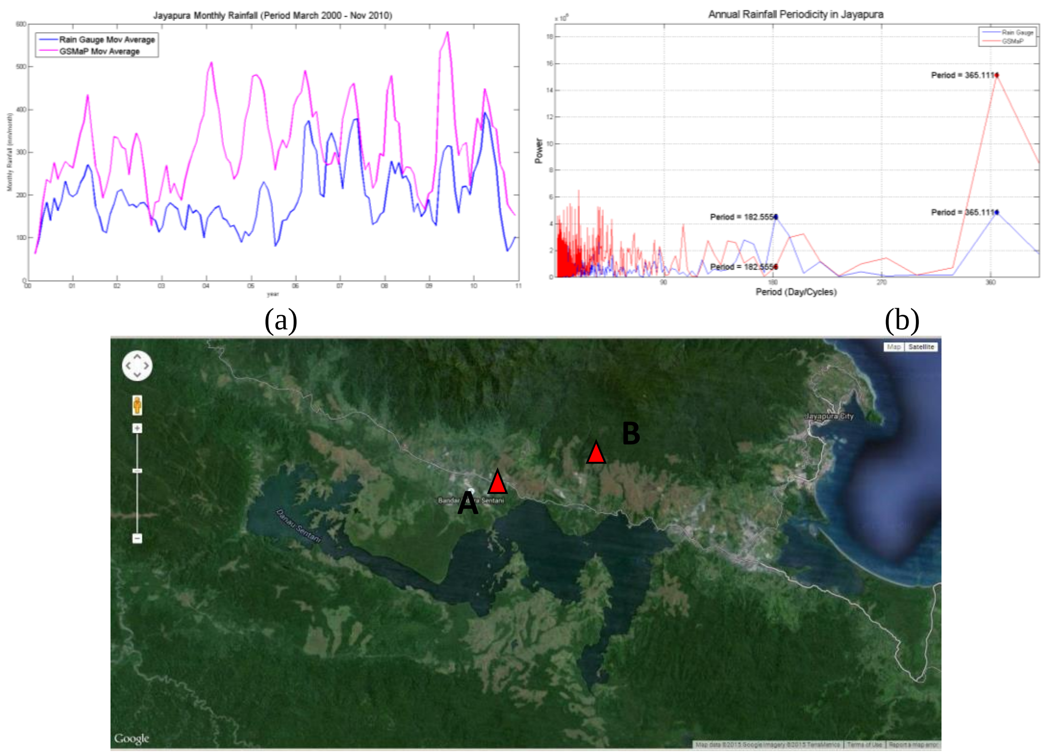


(c)

Figure 7. (a) Monthly rainfall moving average in Palu (b) Annual rainfall periodicity in Palu (c) Topography condition in Palu (https://www.google.co.id/maps)

The unique rainfall characteristic showed in Palu, Central Sulawesi. From the graph of monthly rainfall moving average in Palu (Figure 7a), the high rainfall estimation from GSMaP measuring was shown, but the lower rainfall amount shown in rain gauge measuring, as well in the annual rainfall periodicity, the high magnitude of GSMaP rainfall spectrum was shown, but rainfall spectrum in Palu has a lower magnitude (Figure 7b). Gunawan (2006) discused the local atmospheric circulation which can not be neglected as a rainfall-forming factor in Palu. This region has a unique geographic situation as shown in Figure 7c below. It is surrounded by mountains chains from three directions so that this valley is a leeward region and hence as reported by Braak (1929) the rainfall amount in this region is very limited (600 mm/year). The north side of the Palu Valley faces to the bay and thus, the local atmospheric phenomenon of land sea-breeze circulation dominates the wind direction. Futhermore, Gunawan (2006) said the orographic rainfalls which dominated this area occurs when the air coming from the ocean enters the mountain chain area and orographically lifted cause the rainfall increase with the elevation at the upwind side (the maximum rainfall falls just on the top of the mountain), while at the leeward side the air becomes drier and on its descent the amount of rainfall decreases.

In Figure 7c above, Point A is rain gauge station at 0.92 N 119.91 E and point B is GSMaP point at 0.95 N 119.95 E. The rain gauge station located in a valley at 82 m altitude above the sea level, and the GSMaP point located at 325 m altitude above the sea level at the east mountain ridge measuring by google map. This is the reason why Rain gauge station in Palu has the lower rainfall amount although has the high rainfall estimation from satellite observation. The same rainfall characteristic also showed in Jayapura. The graph of monthly rainfall and annual rainfall periodicity in Jayapura where located in Region A showed very strong annual spectrum on rainfall estimated by GSMaP, but actually had the lower one on the rain gauge, so the GSMaP data characterize overestimate. The high monthly rainfall estimation average shown in the South West Pasific Ocean in Northern Papua almost throughout the year (Figure 10), which influence this area, but actually rain gauge in Jayapura had the lower monthly rainfall average and the rainfall spectrum characterize spread throughout the year with the low magnitude under 10^7 (Figure 8a and 8b).



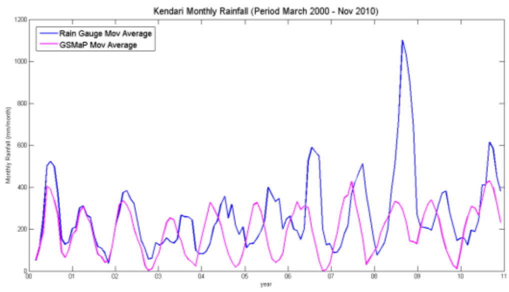
(a) (b)

(c)

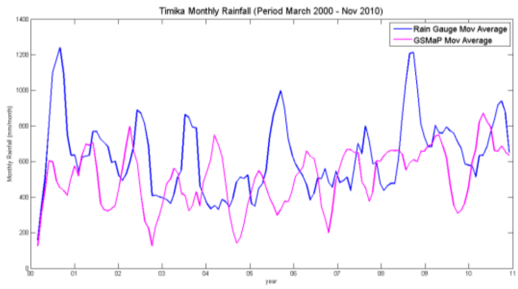
Figure 8. (a) Monthly rainfall in Jayapura (b) Annual rainfall periodicity in Jayapura (c). Topography condition in Jayapura (https://www.google.co.id/maps)

Rain gauge station in Jayapura located in Sentani district at 2.58 S 140.52 E which has a unique tophographic area. By topographic area, rain gauge station in Sentani is located in a valley surrounded by mountains chains in the three direction on the west, north and south and faces the little gap in the east that caused the station has almost same topographical characteristic with Palu.Figure 8c above shows the topography condition in rain gauge station in Sentani. Point A is rain gauge station and point B is GSMaP point at 2.55 S 140.52 E. The rain gauge station located in a valley at 89 m altitude above the sea level at the valley, and GSMaP point located at 346 m altitude above the sea level at the north mountain ridge measuring by google map. So the GSMaP point location has the higher rainfall amount rather than rain gauge station (Figure 8a), and the rainfall spectrum of GSMaP showed higher magnitude than rain gauge (Figure 8b).

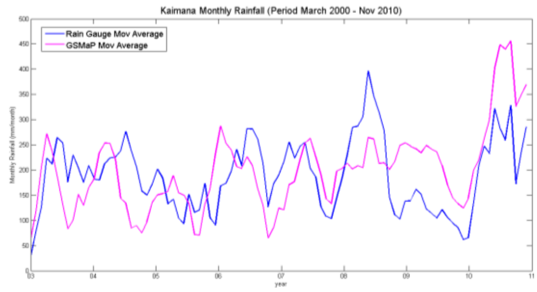
The laging of monthly rainfall measured by GSMaP than rain gauge data were shown in Kendari from early of 2003 – end of 2010 (Figure 9a), in Timika from early of 2001 – end of 2010 (Figure 9b) and in Kaimana on early of 2004 and early of 2006 (Figure 9c). From the map of GSMaP monthly rainfall average estimation were shown in Figure 10, in the waters between Sulawesi and Maluku island around Kendari there was high monthly rainfall on November to March (NDJFM) (150 – 370 mm/month) which indicated a wet season caused by west monsoon, and on April - July (150 – 370 mm/month) which indicated a local factor influenced by high convective zone in Maluku on MJJ. So this area influenced by two rainfall cause factors. While Papua region include Timika and Kaimana, from the monthly rainfall map based on GSMaP data average, high monthly rainfall occurred on December through March (DJFM) as an influenced of monsoon in this area, while in April through November the high monthly rainfall occurred in Papua region as an influenced by South West Pasific atmosphere dynamic as shown in the map.



(a)



(b)



(c)

Figure 9. Moving average of monthly rainfall measured by GSMaP and rain gauge in (a) Kendari, (b) Timika, and (c) Kaimana

The laging of GSMaP data than rain gauge also found by Setiawati *et al.* (2013) which verified hourly GSMaP data in two type file (i.e., GSMaP_MVK and GSMaP_NRT) with rain gauge AMEDAS data and to define the rainfall pattern which causes flood in Kumamoto Prefecture, Japan. They found that the pattern of GSMaP_MVK and AMEDAS was similar, but there was time lag of 9 hours and GSMaP_MVK rainfall data was lower than observed rainfall. Generally, after regionalization of the GSMaP data into three dominant rainfall characteristics include monsoonal type (A), semi-monsoonal type (B), and anti-monsoonal type (C), the monthly rainfall data showed very good agreement with rain gauge monthly rainfall data, the monthly rainfall pattern showed adequately similar with rain gauge monthly rainfall pattern, and the annual rainfall periodicity showed very good agreement in detecting the magnitude of semi-annual and annual rainfall peak power spectrum with rain gauge. The magnitude of rainfall average power spectrum in region A upper than in region B and C that showed in Figure 5. The magnitude of rainfall average power spectrum in region A was upper than 1 x 10^7 otherwise in region B and C were under 1 x 10^7. They indicates that in region A rainfall magnitude is very strong at a wet season while in region B the rainfall magnitude not so strong than in region A but behave spread throughout the year, according in statistical analysis that maximum of the rainfall average in region A was 500.43 mm/month (gauge) where mean was 198.71 mm/month, while in region B maximum was 392 mm/month (in gauge) where mean was 224.71 mm/month. In region C maximum was 323.76 mm/month which mean was 120.58 mm/month (in GSMaP).

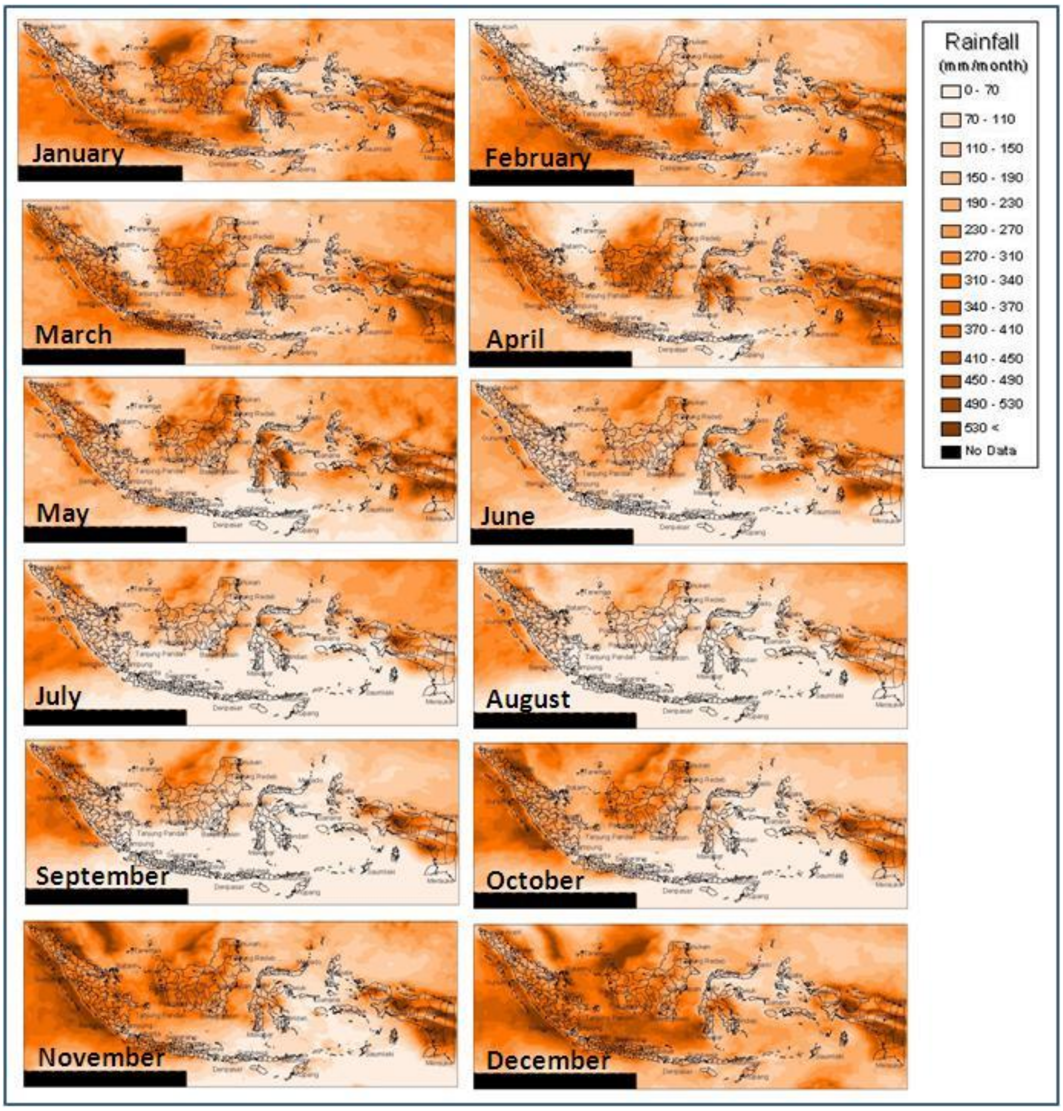


Figure 10. Map of monthly rainfall average measured by GSMaP (period March 2000 – November 2010)

Aldrian and Susanto (2003) used Spectral Analysis Double Correlation Methode (DCM) to describe the annual rainfall periodicity over Indonesian region. Their conclusion had the same characteristics with this research result which use DFT method (Figure 5). The spectrum of Region A has one strong annual signal that dominates the overall rainfall variability in this region with the highest rainfall occurred on January and the smallest one occurred on August in both of GSMaP and rain gauge (Figure 5a). Aldrian and Susanto (2003) said that Region A has one peak and one trough and experiences strong influences of two monsoons, namely the wet northwest (NW) monsoon from November to March (NDJFM) and the dry southeast (SE) monsoon from May to September (MJJAS). The spectrum of Region B has two strong signals, annual (period=11.63 months) and semi-annual (period=6.09 months) signals, with the annual signal being slightly stronger than the semi-annual one in rain gauge, but otherwise in GSMaP the semi-annual signal slighty stronger than annual one (Figure 5b). They indicated that there are two rainfall peak that occures twice a year (on MAM and SON) and one a year (on NDJ). The rainfall peak which occurred twice a year was evidence of rainfall increasing associated with the southward and northward movement of the inter-tropical convergence zone (ITCZ) in this area, while rainfall peak occurred one a year on NDJ indicate a monsoonal influenced.

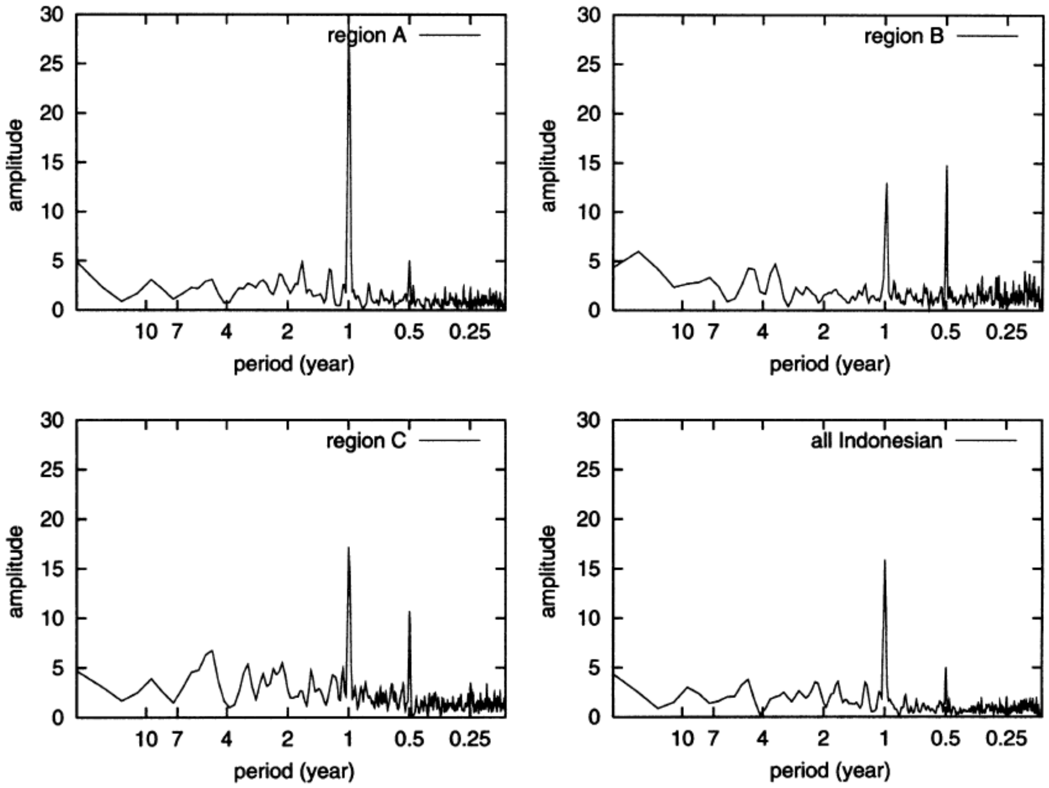


Figure 11. Spectra analysis used DCM (Aldrian and Susanto, 2003)

Aldrian and Susanto (2003) said that Region B has two semi annual peaks, in October–November (ON) and in March to May (MAM). Those two peaks are associated with the southward and northward movement of the inter-tropical convergence zone (ITCZ). Davidson et al., (1984) described in detail the ITCZ movement in this region in boreal winter. There is no clear reason why the peak in ON is much higher than that of MAM. Wyrtki (1987) said there is a possible influence of a cool surface current coming from the north out of the South China Sea during January – March that suppresses the rainfall amount. Futhermore, the spectrum of Region C has two strong peaks and several weaker ones (Figure 5c). Similar to Region A, the annual cycle dominates the rainfall variability of this region. The highest peak showed on MJJ with the smaller one occured on MAM indicated the slighty influence of ITCZ, but not similar in region B, on SON the influence of ITCZ seem disappeared also the monsoonal influence on DJF. WCRP (1998) explained about the high convective zone in Maluku on MJJ, that is one of the explaining about the high convective on May June July (MJJ) is a phenomena that sea surface temperature going warmer in this region. On MJJ, sea surface temperature in West Pasifik and North Eastern Indonesia be warmer than in southern Indonesia. ITF mainly flows through the Makassar Strait (Hirst and Godfrey, 1993; Godfrey et al., 1993) and the waters of Maluku (Rodgers et al., 2000). Indonesian Through Flow (ITF) carries warm flow to Maluku ocean. ITF is a relationship channel flow of sea and ocean of the tropical Pacific ocean Indonesia. Meanwhile Aldrian (2001) said that the opposite phenomena occurs on November December January (NDJ), when ITF carries the cooller flow to Maluku ocean. The coller sea surface temperatur prevent a process of convective zone. So in the region C, there is one upper peak on MJJ and lower peak on NDJ. Generally, from this research, after regionalization of research locations to the three region, rainfall characteristics based on GSMaP data over Indonesian region showed very strong relationship with the regionalization of three dominant rainfall characteristics in Indonesia by Aldrian and Susanto (2003).

5. Coclusion and Suggestion

The validation of satellite showed a good agreement with gauge data over Indonesian, on monthly average rainfall. On the other hand, low medium correlation was shown in the result of of daily average rainfall. This result showed that daily average rainfall was poorly to be adequately served as a stand alone daily climate product. Meanwhile, if GSMaP data were used to cover large areas by averaging, this product was capable to estimate variability of monthly rainfall. Annual rainfall periodicity point to point analysis using DFT showed that GSMaP were reasonably good on detecting the rainfall pattern in monsoonal type (A), but seemed not good to detecting the rainfall pattern in semi-monsoonal type (B) and anti-monsoonal type (C), and also not good in the region which have rainfall pattern that spread throughout the year with lower magnitude of power spectrum. Futhermore, the annual rainfall periodicity after regionalization showed good agreement on detecting the rainfall pattern in all of the Region (A,B, and C). The relationships between monthly rainfall estimation average based on GSMaP after regionalization and monthly rainfall average rain gauge in situ data as refference showed very high correlation, low RMSE and MBE in all of the rainfall characteristics (monsoonal, semi-monsoonal and anti-monsoonal) so from this result we can obtain the correction factor of monthly rainfall average data to correct the value of GSMaP monthly rainfall estimate data. The accuracy of tropical rainfall observation and also estimation be the important factor for the human to understand the atmosphere dinamic, hydrology cycle and climate variability. The quality of satellite rainfall observation and estimation in tropical area needs to be evaluated continually. Further studies are required to validate on annual and inter-annual timescales of the GSMaP product with more parameters such as wind, sea surface temperature, ENSO, Dipole Mode and MJO considering that rainfall is not the only one parameter which can describe the atmosphere dinamic. The better algorithm with higher temporal and spatial resolution required to obtain more accurate and precise of satellite observation considering that many convective precipitation occurs in high intensity on a short time period in the tropics.

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