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Distribution of Accuracy of TRMM Daily Rainfall in Makassar Strait

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Abstract. This research aims to evaluate rainfall estimates of satellite products in regions that have high variations of rainfall pattern. The surrounding area of Makassar Strait have chosen because of its distinctive rainfall pattern between the eastern and western parts of the Makassar Strait. For this purpose, spatial distribution of Pearson's coefficient correlation and Root Mean Square Error (RMSE) is used to evaluate accuracy of rainfall in the eastern part of Kalimantan Island and the western part of Sulawesi Island. Moreover, we used the contingency table to complete the parameter accuracy of the TRMM rainfall estimates. The results show that the performance of TRMM rainfall estimates varies depending on space and time. Overall, the coefficient correlation of TRMM and rain was ranging between -0.06 (no correlation) and 0.78 (strong correlation). The best correlation is on the eastern coast of South West Sulawesi located in line with the Java Sea. While, no variation in the correlation was related to flatland such as Kalimantan Island. On the other hand, in the mountain region, the correlation of TRMM rainfall estimates and observed rainfall tend to decrease. The RMSE distribution in this region depends on the accumulation of daily rainfall. RMSE tends to be high where there are higher variation of fluctuating rainfall in a location. From contingency indicators, we found that the TRMM rainfall estimates were overestimate. Generally, the absence of rainfall during the dry season contributes to improving TRMM rainfall estimates by raising accuracy (ACC) in the contingency table.

Keywords: rainfall pattern, accuracy of TRMM, monsoon, Indonesia, Makassar Strait.

Abstrak. *Penelitian ini bertujuan untuk mengevaluasi estimasi curah hujan dari satelit di daerah yang pola hujannya bervariasi. Daerah di sekitar Selat Makassar dipilih karena perbedaan pola hujannya antara sebelah timur dan barat selat tersebut. Untuk tujuan ini digunakan distribusi spasial koefisien korelasi and Root Mean Square Error (RMSE) untuk mengevaluasi akurasi curah hujan di bagian timur Pulau Kalimantan dan di bagian barat Pulau Sulawesi. Selain itu digunakan juga table kontigensi untuk melengkapi parameter akurasi estimasi curah hujan TRMM. Hasilnya menunjukkan curah hujan TRMM bervariasi tergantung ruang dan waktu. Secara keseluruhan, koefisien korelasi harian antara TRMM dan curah hujan observasi dari tidak berkorelasi yaitu -0.06 sampai berkorelasi kuat 0.78. Korelasi terbaik di bagian pantai timur Sulawesi Barat Daya yang terletak segaris dengan Laut Jawa. Sebaliknya terdapat tempat yang hampir tidak bervariasi korelasinya di daerah datar seperti di Pulau Kalimatan. Kebalikannya di daerah pegunungan korelasi TRMM cunderung turun. Berdasarkan table kontigensi ditemukan estimasi curah hujan TRMM harian lebih tinggi. Umumnya, ketiadaan hujan selama musim kemarau berkontribusi terhadap perbaikan akurasi TRMM dengan meningkatnya accuracy (ACC).*

Keywords: *curah rainfall pattern, accuracy of TRMM, monsoon, Indonesia, Makassar Strait.*

1. Introduction

The Indonesian maritime continent has a unique weather pattern and, more especially, in relation to its rainfall characteristics. Although monsoon is the most influential global weather circulation, this region is affected, also, by other global weather circulations. Weather circulations, such as El Niño/Southern Oscillation (ENSO), Madden Julian Oscillation (MJO), Indian Ocean Dipole (IOD), have significant impacts on the Indonesian region (D'Arrigo and Wilson, 2008; Hidayat and Kizu, 2010; As-syakur, 2010; Lee *et al.*, 2015, Martono and Wardoyo, 2017; Supari *et al.*, 2017). This area consists of thousands of islands, hundreds of mountains, some seas, and straits that can affect local weather circulation. Consequently, the complexity of weather circulation increases especially in rainfall patterns (Neale and Slingo, 2003). Each place has its own characteristics of onset, peak, withdrawal monsoon and distribution of rainfall (Aldrian and Susanto, 2003; Giarno *et al.*, 2012). One part of Indonesian, which has a highly variable rainfall pattern, is the area surrounding the Makassar Strait. Based on rainfall data observations from the Indonesian Meteorological Agency (BMKG), the annual rainfall in the west part of the Makassar Strait is more than 2000 mm while, in the eastern part, it varies from below 1000 mm to more than 2000 mm. The southern part of this region has a clear distinction between wet and dry seasons, and these seasons tend to be unclear towards the equatorial region (Aldrian and Susanto, 2003; Aldrian *et al.*, 2007).

Rainfall is an important variable in hydrology and, for many necessities, rainfall data measured at a location are assumed to be the most accurate. Therefore, the location of rainfall equipment is expected to be representative of the surrounding area and show a reliable spread. For this reason, the World Meteorological Organization (WMO) determines the different terms of the placement of equipment. On the other hand, the range of placement of rain gauges depends on the surface condition (WMO, 1994). Commonly, this requirement cannot be fulfilled in the Indonesia region. Interpolation can be used to estimate for ungauged locations; however, the use of interpolation for ungauged locations can raise uncertainty and, more especially, in desert and hilly areas (Mair and Fares, 2004; Thiemig *et al.*, 2012). Consequently, one of the solutions when estimating ungauged places is remote sensing measurements of such rainfall satellites (Hsu *et al.*, 1997; Sorooshian *et al.*, 2000; Joyce *et al.*, 2004; Huffman *et al.*, 2007; Xie *et al.*, 2011).

Commonly, the satellite has either a global or quasi-global orientation and, therefore, the performance tends to vary from one place to another (Kneis *et. al.*, 2014; Mahmud *et. al.*, 2015). Moreover, verification is required to examine rainfall estimates, the improvement of quality prediction and the process itself (Mariani and Casaioli, 2008). In order to verify a satellite, pixels are compared with the measurement of surface rainfall and show that there are variations of accuracy of satellite estimates (Liechti *et al.*, 2012; Moazamia *et al.*, 2013). Although TRMM estimates are not particularly accurate because of the spatial scale effect, daily resolution and the island complexity (Rahmawati and Lubczynski, 2017), some parts of Asia show better TRMM rainfall estimates than others (Li *et al.*, 2012; Xue *et al.*, 2013; Hu *et al.*, 2014). Not surprisingly, TRMM is used in a lot of hydrology analysis (Rahman *et al.*, 2012).

The Indonesian rainfall pattern was often noted from the evaluation of Monthly TRMM rainfall estimates. For this purpose, monthly graphics is usually used to distinguish the rainfall pattern. The peak season of rainfall is in December, January and February and is known as the monsoonal pattern. On the other hand, the local pattern is nearly similar to the monsoonal pattern but the peak of the rainy season is in June, July and August. Finally, if the monthly graphic of rainfall is unable to distinguish the monsoonal or local pattern clearly, it is known as the equatorial pattern (Aldrian and Susanto, 2003). For the sake of simplicity, the area of the monsoonal and local pattern includes Zone of Season (ZOM) while the area of the equatorial pattern includes Non-Zone of Season (Non-ZOM) (BMKG, 2015).

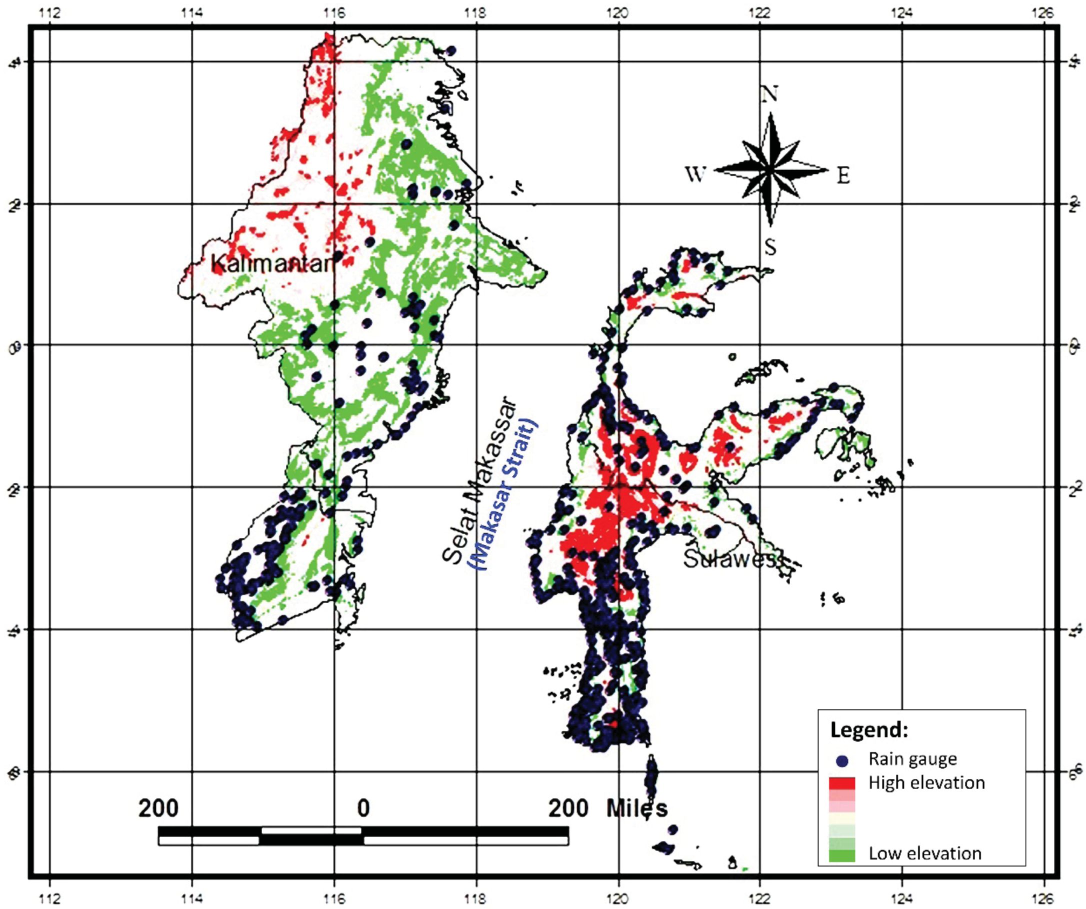

Figure 1. Locations of rain gauge in surrounding Makassar Strait, Kalimantan (western) and Sulawesi (eastern). Sulawesi has more mountains (red colour) than Kalimantan, while Kalimantan is dominated by terrain below 1,000 meters (green and white colour).

When the TRMM estimates and rainfall, observed in 4 monsoonal areas (Indramayu, Makassar, Malang and Medan) are compared, it shows a high correlation between TRMM rainfall estimates and the *in situ* rainfall data (Gunawan, 2008). However, if more locations are used for comparative purposes, it leads to a different conclusion (Prasetia *et al.*, 2013). Correlation of TRMM rainfall estimates in the monsoonal and the local pattern area tends to be better than the equatorial pattern. Consecutively, the correlation in the monsoonal area is between 0.33 and 0.73; the local area is between 0.16 and 0.58, and the equatorial area is between 0.07 and 0.52. Meanwhile, in the local pattern area, the Root Mean Square Error (RMSE) value does not fluctuate as much as in the monsoonal and the local pattern area.

Furthermore, validation of TRMM against rain gauge data shows that monthly scale provide higher correlation compare to daily scale (As-Syakur *et al.*, 2010; Prasetia *et al.*, 2013). It is important to provide a deeper understanding of the accuracy of TRMM in daily scale considering above variations. Hence, this study evaluates the daily spatial distribution of TRMM accuracy and the effect of time rainfall accumulation on the Indonesian maritime continent. We chose the Makassar Strait because of its variable of rainfall pattern. This research's principal objective is to advance understanding of the capability of TRMM rainfall estimates on the maritime continent that has different rainfall characteristics.

2. Research Method

2.1. Data

The Makassar Strait is located between two large islands. There are Sulawesi Island on the east side and Kalimantan Island on the west side. The Sulawesi Sea at the north and the Java Sea at the south form the Makassar Strait. Between two islands, the Kalimantan Island is a much flatter region than the Sulawesi

Island. Moreover, except in the northeast, the Kalimantan Island's lowland area is less than 1,000 m. On the other hand, the Sulawesi Island is mountainous and has a few plain areas. The lowland area is located on the Island's long coast and some places that have separate mountains. The areas, which separate central and southern Sulawesi, central and northern Sulawesi and some places between the mountains in the central Sulawesi have elevations below 1,000 m. The Asian and Australian Monsoon influences greatly this region's rainfall.

The rain gauge measurement is located only in the eastern and western parts of the Makassar Strait. This instrument is placed on Kalimantan Island and Sulawesi Island (Figure 1). Badan Meteorologi Klimatologi and Geofisika (BMKG), collects the Indonesian *in situ* weather data and, more especially, the rainfall data. In 2015, there were more 600 rain gauges in this location and most of rain gauges were located on Sulawesi Island. If a location's annual missing rainfall data is above 10 %, the data was excluded from the analysis. For evaluation purposes, observed rainfall was compared with daily TRMM rainfall estimates that are available at ftp://disc2.nascom.nasa.gov/data/TRMM/Gridded/.

2.2. Evaluation method for TRMM rainfall estimates

A comparison between satellite rainfall estimates and *in situ* data can be done either visually or by pixel comparison (Wealands *et al.*, 2004). The first technique is a direct visual comparison and the consistent quantity of the results in depends on the researcher's experience. On the other hand, pixel comparison is more objective and has been used widely to verify rainfall estimates from a remote sensing product such as satellite and radar. Satellite rainfall estimates are shown in a pixel for an area while the rainfall from a rain gauge is shown as a point value. Verification is done by searching the nearest rainfall of the satellite pixel to the location of the rain gauge (Liu *et al.*, 2015). One pixel satellite can contain more than one *in situ* rainfall data. Some researchers pick up only one location in one pixel in order to verify the rainfall satellite pixel whereas others use an average of rainfall *in situ* data. In this work, rainfall is not adjusted to the surrounding measurements and, therefore, all rainfall *in situ* data is used when considering the complexity of the topography and the rainfall pattern. The result is analysed to show the performance of TRMM rainfall estimates.

Verification uses two common statistic indicators namely Pearson coefficient correlation (r) and RMSE calculated by using Equation 1 and 2 respectively. Where R_r refers to rainfall from rain gauge, $\overline{R_r}$ refers to average of R_r, R_S refers to satellite rainfall estimates, $\overline{R_S}$ refers to average of R_S, n refers to total of rain gauge station and i refers to station index. Classification of correlation r uses absolute value of r value and is divided into 4 classes. There are no correlation ($r < 0.09$), weak correlation ($0.1 < r < 0.299$), moderate correlation ($0.3 < r < 0.499$) and strong correlation ($r > 0.5$) (Prasetia *et al.*, 2013).

$$r = \sqrt{\left[\frac{\sum_{i=1}^{n}\left(Rr_i - \overline{Rr}\right)\left(Rs_i - \overline{Rs}\right)}{\sqrt{\sum_{i=1}^{n}\left(Rr_i - \overline{Rr}\right)^2}\sqrt{\sum_{i=1}^{n}\left(Rs_i - \overline{Rs}\right)^2}}\right]^2} \qquad (1)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}\left(Rr_i - Rs_i\right)^2}{n}} \qquad (2)$$

A contingency table is added in order to complete the evaluation analysis. This method is useful for the occurrence of rain verification. It is easier to detect the existence of a specific event, such as a rain event, by using a contingency table than only using correlation and RMSE (Jolliffe and Stephenson, 2003). As shown in Table 1, the contingency table has 4 criteria. Hits refer to the number of observed precipitations and satellites that state rain. Next, false alarm refers to the number of satellite rainfall estimates that states rain but when the rain gauge has not observed precipitation. Misses refers to the number of satellite rainfall estimates that do not state rain but when the rain gauge observed precipitation. Finally, correct negative refers to the number of both observed precipitation and satellite states of not rain.

Table 1. Contingency Table for Rain Event Detection.

Tool		Rain gauge	
	Event	**Rain**	**No rain**
TRMM	Rain	Hits	False alarm
	No rain	Miss	Correct negative

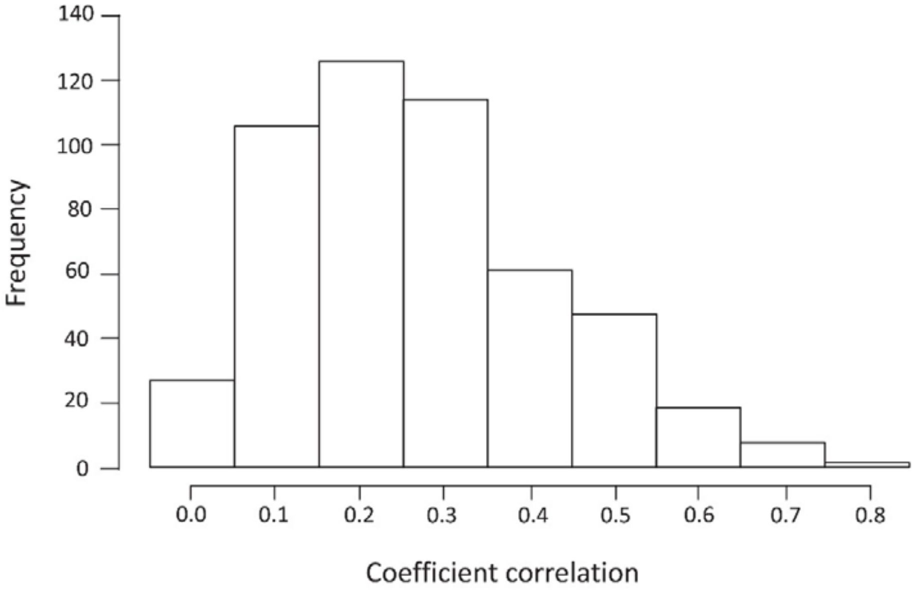

Figure 2. Frequency distribution of daily correlation between TRMM rainfall estimates and observed rain in 2015.

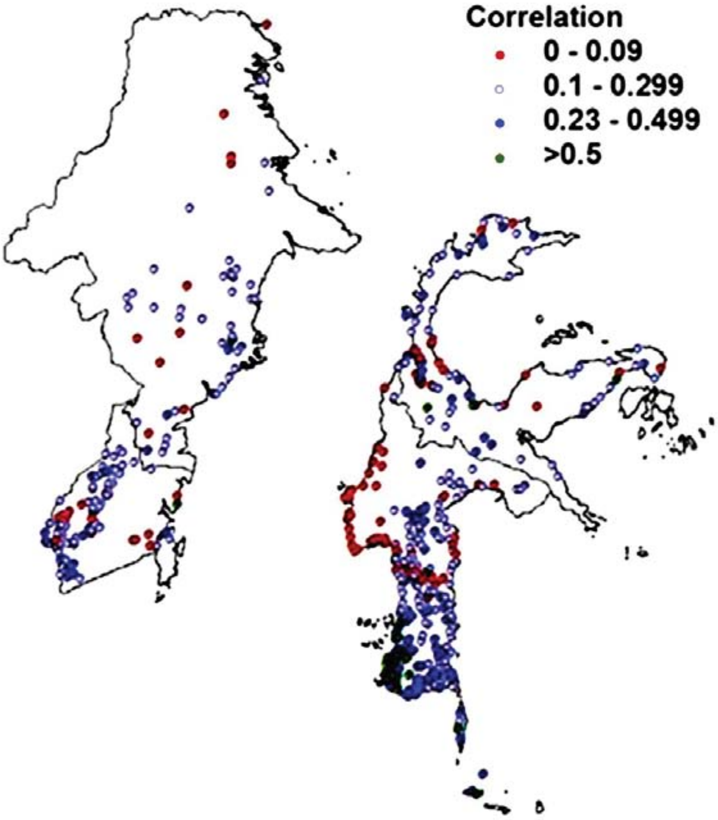

Figure 3. Spatial distribution daily correlation between TRMM and gauged rainfall estimates. These are no correlation (red circle), weak correlation (grey circle), moderate correlation (blue circle) and strong correlation (green circle).

The statistical contingency indicator includes ACC (Accuracy), BIAS, FAR, POD and CSI (Equation 3 to 7). The ACC value refers to the fraction of correct estimation whereby the best and the worst values are 1 and 0 respectively. Moreover, ACC is easy to interpret, but it can be misleading for the most common event. On the other hand, BIAS refers to the ratio of the frequency of estimated events to the frequency of observed events. Hence, BIAS can detect an underestimated or overestimated event. BIAS' perfect value is 1. Furthermore, POD refers to the ability to correctly estimation in certain categories and can be useful in the case of a severe weather event. Thus, the FAR measure suggests a satisfactory estimation and, more especially, a severe weather event. Finally, CSI, known as the threat score, refers to how numbers correct event divided by the number of estimated cases for that category. This indicator can measure relative accuracy.

$$ACC = \frac{Hits + Correct\_Negative}{Total} \tag{3}$$

$$BIAS = \frac{Hits + False\_Alarm}{Hits + Miss} \tag{4}$$

$$POD = \frac{Hits}{Hits + Miss} \tag{5}$$

$$FAR = \frac{False\_Alarm}{Hits + False\_Alarm} \tag{6}$$

$$CSI = \frac{Hits}{Hits + Miss + False\_Alarm} \tag{7}$$

There is no single indicator of statistical contingency that can be used to determine the performance of prediction. ACC is sensitive to a dominant event, such as either a tornado event or a rain event in the desert. However, it is still useful to detect the emergence of rain events in areas where the number of rain events and not rain are relatively balanced such as a rain event in Indonesia. BIAS is affected greatly by the number of false alarms and misses. POD is sensitive to false alarms while FAR is sensitive to misses. Then, there is the CSI neglected correct negative which is very sensitive to misses and false alarms.

Indonesia's daily rain events almost balance with the no rain events. Consequently, this research uses all the statistical contingency indicators. The test of the event prediction is done not only for a severe event, such as a tornado (Murphy, 1993), but also in all rain events which follow the BMKG criteria. Moreover, daily rainfall is classified as follows; very light rain is if the daily rainfall intensity is between 0 and 5 mm; light rain is between 5 and 20mm; moderate rain is between 20 and 50mm; and heavy rain is more than 50mm (BMKG, 2015). In this work, the class of light rain is expanded by adding daily intensity of 10 mm rainfall.

We calculated correlation and RMSE on a daily basis at each rain gauge location so that the results can be used to denote the spatial distribution of TRMM performance. We separated daily TRMM rainfall estimates on a monthly basis in order to determine the changes in monthly accuracy. Furthermore, verification considers the temporal accumulation in detecting the impact of rainfall accumulation. From the hundreds of selected rain gauges, we calculated all statistical indicators each a day and at three day, 5 day, 10 day and monthly intervals. On the evaluation of rainfall accumulation, we completed each of the required accumulated temporal rainfall data. If the accumulated data was incomplete, it was not taken into account. Then, we classified the results and depicted them in a graph for analysis.

3. Results and Discussion

3.1. Daily performance of TRMM rainfall estimates

The results of daily performance of TRMM to estimate rainfall are provided in both frequency bar chart and spatial distribution (map). Figure 2 depicts the distribution of the daily correlation between TRMM rainfall estimates and rain gauge observations in the area surrounding the Makassar Strait. These are between -0.06 and 0.78. Generally, there is weak to moderate correlation of the TRMM rainfall estimates in this area. However, from the rainfall observed in 2015, a number of places have strong correlations while other areas have no correlation.

There is a significant difference in the distribution of correlation between the eastern and western part of the region surrounding the Makassar Strait. In some places, there is no correlation between estimation and observation while, in others, there is a strong correlation between them (Figure 3). The correlation distribution is more varied in the east part of the Makassar Strait than in the west part. Commonly, the correlation of Sulawesi Island ranges from no correlation to strong correlation while, on the Kalimantan Island, it ranges from weak correlation to moderate correlation.

TRMM rainfall estimates in the monsoonal region, such as South Sulawesi, are good enough on the monthly scale. That is shown by high correlation of monthly TRMM rainfall estimates in South Sulawesi such as the Makassar city (Gunawan, 2008; Prasetia *et al.*, 2013). However, if the research area increases, the accuracy varies according to space and time. Moreover, because it has more complex topography, the correlation distribution of Sulawesi Island is more varied than Kalimantan Island.

On the Sulawesi Island, the correlation value tends to be strong in the south and weak in the middle. The strongest correlation is located along the east coast of South Sulawesi. This region is plain land and is connected to the Asian monsoon. This is because the wet Asian monsoon, which carries a lot of water vapour, makes a lot of rain in southern Indonesia. The moist wind blows from west to east of the Java Sea's wide waters and makes persistent rain events in South Sulawesi. With its high correlation, TRMM can detect this rain along the east coast of South Sulawesi. However, elsewhere, TRMM rainfall estimates and observed rainfall vary from uncorrelated to strongly correlated. It may be that the TRMM's performance is affected by the local weather circulation.

The mountains in the middle of South Sulawesi seem to act as a barrier to the wind of the Asian monsoon. The reduction of the Asian monsoon's influence increases the effect of local circulation and it can be detected by TRMM because local circulation has a smaller resolution than TRMM. Apparently, the topography of the area, such as mountains, affects the accuracy of the correlation (Yuan *et al.*, 2017). On the contrary, nearly no correlation is found along the east coast of Middle Sulawesi. Also, the weakest correlation of TRMM rainfall estimates and gauge observations is found in the mountains of Middle Sulawesi and the correlation increases to the north part of this island. Other local factors, such as sea breeze, have an effect on rainfall. Some coastline regions of the tropics have a sharp rainfall gradient because of both local circulations and large scale weather systems (Heiblum *et al.*, 2011; Biasutti *et al.*, 2012). Moreover, in the complex tropical region, it is possible to make the weakening correlation between TRMM rainfall estimates and gauge observations.

Distribution of correlation is almost similar from weak to moderate in either the western part of the Makassar Strait or on the Kalimantan Island. However, although its correlation is not as high as along the east coast of South Sulawesi, South Kalimantan has a relatively higher correlation than other parts of Kalimantan. There is some moderate correlation in South Kalimantan which is connected to the Java Sea and farther to the equatorial line than other part of Kalimantan. Hence, it does have a stronger influence on rainfall from the Asian monsoon than in other parts of Kalimantan. Towards the equatorial line, the rainfall pattern becomes the equatorial pattern and results in declining TRMM rainfall estimates (Prasetia *et al.*, 2013; Tan *et al.*, 2015).

Correlation changes happen not only in the area surrounding the Makassar Strait but also each place performs differently in terms of TRMM rainfall estimates. Both correlation and RMSE or other indicators can differ from one place to another. This was also illustrated in some research studies such as by Bangladesh (Rahman *et al.*, 2012), China (Tang *et al.*, 2016), Iran (Sharifi *et al.*, 2016), Korea, Japan (Kim *et al.*, 2017) and Singapura (Tan and Duan, 2017).

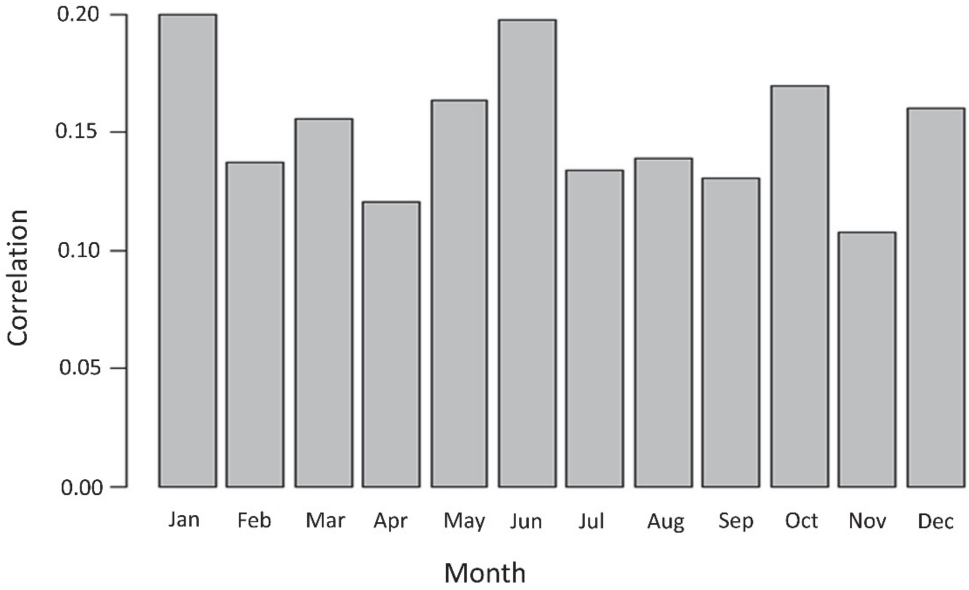

Figure 4. Collected daily correlation in a month between TRMM and Gauged rainfall estimates.

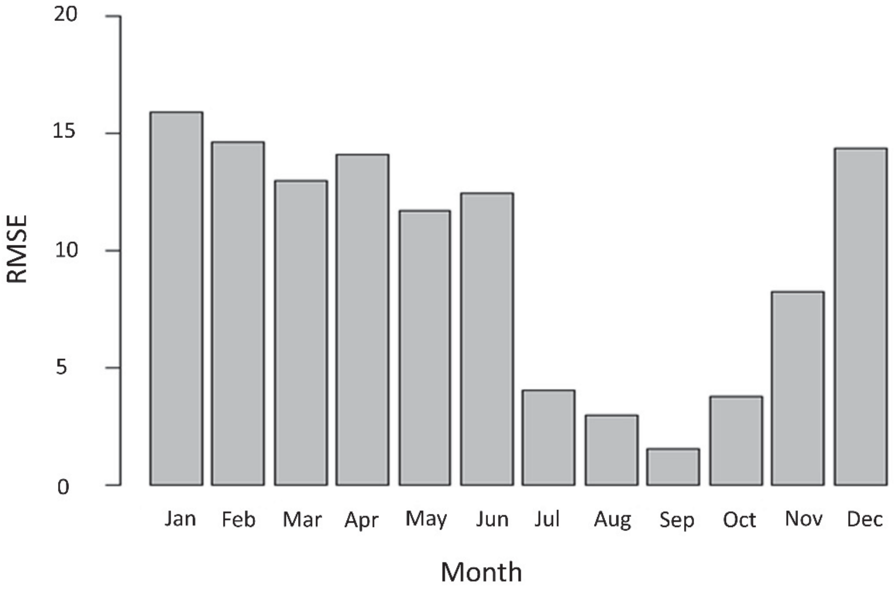

Figure 5. Collected daily RMSE in a month between TRMM rainfall estimates.

As shown in Figure 4, based on separate daily correlations collected at monthly intervals, this region's rainfall varies over time. Apparently, the correlation of this region is not related directly to the rainy or dry seasons. The high correlation value can be found either in January and February, which is the peak of the rainy season, or in June which is the dry season. Even in the transition months of the seasons, such as in May and October, the correlation value can be high enough. Whereas the lowest correlation may relate to the dry season in July, August and September when there is no rainfall. If the estimated rainfall TRMM is calculated by monthly accumulation, it obtains the average correlation value of 0.7 and the negative correlation can be obtained. Prasetia *et al*. (2013) showed that in the local and the equatorial rainfall pattern region the negative correlation can happen, especially in March, April and May.

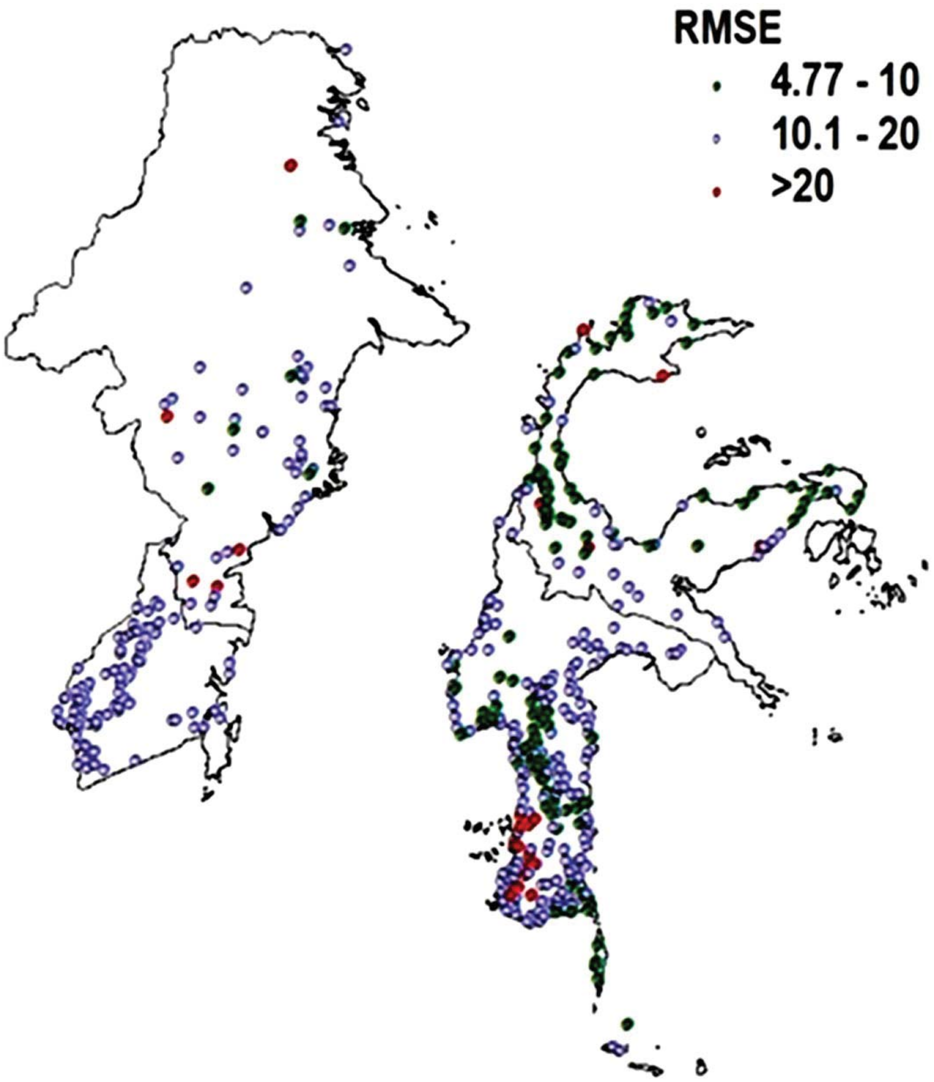

Figure 6. RMSE Spatial daily distribution between TRMM rainfall estimates.

Table 2. Value of contingency indicators of temporal rainfall accumulation in 2015.

Indicator	Daily	3 days	5 days	10 days	Month
ACC	0.75	0.75	0.83	0.82	0.76
BIAS	1.20	1.20	1.00	1.11	1.23
POD	0.85	0.85	0.90	0.93	0.95
FAR	0.29	0.29	0.10	0.16	0.23
CSI	0.37	0.63	0.81	0.79	0.74

RMSE identifies the distinctive value between TRMM rainfall estimates and observed gauged rainfall. As shown in Figure 5, the separation of daily correlations at monthly intervals shows that in most places daily RMSE is between 10 mm to 15 mm and then 0 mm to 10 mm. The highest RMSE happens in December, January, February and April. On the other hand, December, January and February represent the rainy season when the Asian Monsoon rainfall has a strong influence on the Indonesian ZOM area. Consequently, it can be concluded that there is a strong relationship between the increasing errors in TRMM rainfall estimates and the increases in rainfall intensity. On the other hand, there is a strong relationship between the reduction of errors in TRMM rainfall estimates and the reduction in rainfall intensity.

Table 3. Distribution of rain intensity in 2015 by monthly distribution.

Month	**2015**						
	N/A	**No Rain**	**0-5**	**5-10**	**10-20**	**20-50**	**>50**
Jan	0.8%	52.6%	13.4%	8.9%	10.4%	10.4%	4.2%
Feb	0.2%	53.1%	13.0%	8.7%	10.5%	11.0%	3.7%
Mar	0.6%	59.0%	12.3%	7.8%	9.0%	9.0%	3.0%
Apr	0.7%	58.3%	12.2%	7.4%	8.8%	9.9%	3.4%
May	0.4%	67.4%	10.8%	6.1%	7.0%	6.5%	2.1%
Jun	0.2%	59.6%	13.5%	7.8%	8.4%	7.8%	2.9%
Jul	0.6%	87.3%	6.0%	2.6%	2.0%	1.4%	0.6%
Aug	0.0%	93.4%	3.5%	1.3%	0.9%	0.8%	0.2%
Sep	1.1%	97.2%	1.3%	0.4%	0.5%	0.3%	0.1%
Oct	0.3%	92.4%	3.2%	1.5%	1.4%	1.3%	0.2%
Nop	0.7%	72.5%	10.1%	5.2%	5.8%	5.2%	1.3%
Dec	14.9%	57.2%	12.1%	7.4%	8.7%	10.6%	4.0%
Sum	2%	70%	9%	5%	6%	6%	2%

Table 4. Value of Contingency Indicators based on rainfall intensity in 2015.

Indicator	No rain	0-5	5-10	10-20	20-50	>50
ACC	0.53	0.72	0.87	0.86	0.87	0.96
BIAS	1.01	0.65	1.09	1.28	1.50	1.74
POD	0.61	0.13	0.07	0.09	0.09	0.03
FAR	0.40	0.53	1.02	1.19	1.42	1.71
CSI	0.43	0.08	0.03	0.04	0.04	0.01

Figure 6 depicts the RMSE's spatial distribution. Generally, on the Sulawesi Island, RMSE is more varied than on the Kalimantan Island. The details are as follows. First, RMSE distribution on the plain land, such as Kalimantan Island, tends to be similar between 10 – 20 mm. This is no different to the southern part and other parts of Kalimantan. Moreover, the smallest RMSE is found near the equator because, in this region, an equatorial rainfall pattern happens for almost the whole year. Second, in the complex land such as Sulawesi Island, the most RMSE is also 10 – 20 mm. However, the best RMSE or the smallest RMSE is found more in Central and Northern Sulawesi. This is different to Prasetia *et al.*'s (2013) findings that Palu (Middle Sulawesi) has a higher RMSE than others parts surrounding the Makassar Strait. Moreover, the low RMSE is found in plain land that separates the Southern and Central parts of Sulawesi Island, plain land in Central Equatorial Sulawesi and along the east coast of South Sulawesi.

Contingency indicators, such as ACC, BIAS, POD, FAR and CSI, are used to establish the accuracy of the daily TRMM rainfall estimates of rain events. As shown in the first column of Table 2, the daily rain event detection of TRMM varies over time. In 2015, TRMM is good enough to detect either a rain or no rain event where its ACC value is 0.75. However, for better conclusions, this indicator must be accompanied by other indicators such as BIAS, FAR, POD and CSI. On the other hand, the indicators can be used to add the information to what event can make ACC high. Table 2's information shows that the BIAS indicator is greater than 1 but there is a very small FAR value. It means that the numbers of false alarms happen more than either the numbers of missing events or the overestimation of TRMM rainfall estimates. In addition, a very small CSI indicates that the correct negative makes a significant contribution to ACC value.

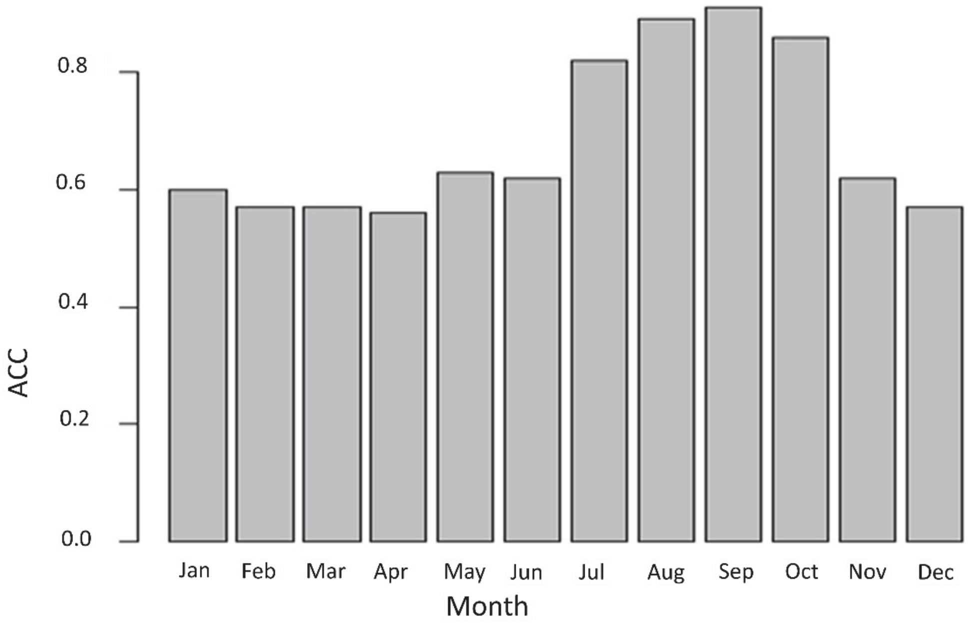

Figure 7. Monthly ACC of TRMM rainfall estimates.

3.2. Temporal rainfall accumulation and rainfall intensity performance of TRMM

Detection rain event using TRMM is better when accumulated rainfall is calculated longer than daily periods (Tables 2 and 3). The ACC and CSI values increase from daily, 3 days, 5 days, 10 days and monthly rainfall accumulation and reduce slightly at monthly intervals. There is a tendency for the TRMM rainfall estimates to be better over long accumulation of rainfall. Moreover, over longer periods, there are nearly perfect scores for others indicators such as BIAS, POD, FAR and CSI. However, there is a reduction in indicator accuracy at 10 day and monthly accumulations. There are decreasing on the values of ACC and CSI together with BIAS and FAR values. Based on the characteristics of BIAS and FAR formulations, there are increasing numbers of false alarms. In other words, 10 day and monthly accumulations lead to overestimations of TRMM rainfall estimates.

Based on the distribution of rain intensity, it shows that only 30% of all the days in 2015 are rain days or, generally, in this year no rain events are more dominant than rain events (Table 3). Very light rain event (0–5mm/day) is higher than other intensities. Moreover, in 2015, there is a clear distinction between the rainy season and dry season. There is very little rainfall in the peak of the dry season such as in August, September and October and, in those months, no rain event reaches more than 90%. On the contrary, in the rainy season, rainfall is not so dominant. Moreover, heavy rainfall happens often in December, January and February when rainfall from the Asian monsoon is dominant.

Verification of occurrence of rainfall shows that the accuracy (ACC) increases with respect to rain intensity (Table 4). However, an increased ACC is accompanied by reductions in other indicators and this shows that there is something improper with the detection. Moreover, the CSI's small value, which coincides with the ACC's large value, indicates that the higher the rainfall intensity, the higher the CN value. The small proportion of Hit events can be seen from the small number of POD values along with the increase of rainfall intensity. When the BIAS and FAR values tend to be above 1, it indicates that a false alarm event is increasingly dominant with increasing rain intensity on TRMM rainfall estimates.

In 2015 and, commonly in all conditions of intensity, TRMM rainfall estimates tended to make overestimation mistakes in 2015. The BIAS value is almost above 1. This can happen when the satellite warned rain but the rain gauge did not detect a rain event. The use of

TRMM in rainfall estimates can result in either overestimates or underestimates. The variable performance to detect a rain event happens not only in this region but also in other places such as Malaysia, India, and China (Tan *et al*., 2015; Prakash *et al*., 2015; Guo *et al*., 2016). The magnitude of either overestimation or underestimation varies with time and places (Guo *et al*., 2016).

However, contingency indicators, used in this region, can be sensitive in showing a dominant event. This is mainly in the dry season when no dominant rain event increases the ACC (Figure 7). The values in the period from July to October are higher than 0.8. This condition means that the higher ACC value of comes from the absence of rain in the dry season. Also, the peak of the rainy season is in January when the rain event is dominant but does not increase the ACC automatically.

4. Conclusion

This study added a preliminary assessment product of TRMM rainfall estimates in temporal accumulation over areas with different rainfall characteristics such as those surrounding the Makassar Strait. It was noted that the added intensity of rainfall resulted in changes to accurately estimating the intensity. Moreover, for verification purposes, we used common statistical indicator correlation and RMSE and ACC, BIAS, POD, FAR and CSI statistical contingency indicators. This study's conclusions are summaries as follows: (1) TRMM rainfall estimates vary depending on time and place. In the plain land, such as on Kalimantan Island, there is little variation between correlation and RMSE. It is different with a complex region, such as Sulawesi Island, which has a greater variation in correlation and RMSE. (2) The Asian monsoon affects TRMM rainfall estimates. The moist wind from the Asian monsoon, which carries a lot of water vapour, makes the rain more durable. TRMM can detect this rain along the east coast of South Sulawesi where TRMM rainfall estimates and rainfall observations rainfall have a high correlation. (3) Local factors, such as the size of waters and the position where the moist wind comes from and mountains influence TRMM rainfall estimates. The small scale of local circulation is suspected to effect the detection of TRMM rainfall. (5) Performance of TRMM rainfall estimates can be improved by using longer accumulation periods. Correlation and statistical contingency indicators, such as ACC, BIAS, POD, FAR and CSI are inclined towards a perfect value. (6) Based on contingency indicators and, more especially BIAS, it is more common to overestimate TRMM rainfall estimates in all classes of intensity. This work used only one year's daily rainfall data that might subject to limitation. Hence it is interesting if, in future, work is extended to more years and wider regions. This work is especially relevant in complex maritime continent regions such as Indonesia.

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