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International Telecommunication Union-Radiocommunication Sector (ITU-R) P.837-6 and P.837-7 performance to estimate Indonesian rainfall

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ABSTRACT

This work evaluated the performance of International Telecommunication Union-Radiocommunication Sector (ITU-R) P.837-6 and P.837-7 models (Annex 1) to estimate one-minute rainfall rates in Indonesia. In addition to the default ITU-R P.837-6, the input of ITU-R P.837-6 is also modified using data which has better spatial resolution, i.e. a combination of Tropical Rainfall Measuring Mission (TRMM) 3A25 and 3B43 (ITU-R+3A25+3B43), 3B42 and 3B43 (ITU-R+3B42+3B43), Global Satellite Mapping of Precipitation (ITU-R+GSMaP), and Global Precipitation Measurement (ITU-R+GPM). Among the five test sites, the default ITU-R P.837-6 and ITU-R+3A25+3B43 could predict one-minute rainfall rates at two locations accurately. The ITU-R P.837-7 exhibited a marginally better performance for sites that had a high percentage of very heavy rain, particularly at large (1%) and small (0.001%) percentages of time exceeded. The spatial distribution of rainfall rate produced by ITU-R P.837-7 and ITU-R+3A25+3B43 was closer to the pattern demonstrated by recent satellite precipitation measurements.

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1. INTRODUCTION

Knowledge of one-minute cumulative distribution of rainfall rates is required to estimate signal loss, which is essential in rain fade models, for planning both satellite and terrestrial links that utilize microwave and millimeter wave bands [1]. Although rain is not the only factor that influences signal propagation in these bands, it causes larger attenuation than other atmospheric components [2]. To calculate one-minute rainfall rate statistics accurately, measurement data with one-minute integration time are required. However, this proves to be difficult occasionally because the available measurement data often utilize a longer integration time. Therefore, one-minute rain rate statistics are frequently derived from such data with certain conversion techniques [3-5], or using statistical models [1, 6-8].

The International Telecommunication Union-Radiocommunication Sector (ITU-R) P.837 has been widely used for calculating one-minute rainfall rates. In 2013, the ITU released the ITU-R P.837-6, which utilized the annual rainfall rates from 40 years of data from the European Center of Medium-range Weather Forecast (ECMWF) with a spatial resolution of 1.125◦ and six-hour temporal resolution [1]. Low resolution of the input data might affect the accuracy of this model [9]. This limitation was overcome by modifying ITU- R P.837-6 using data with better resolution. The tropical rainfall measuring mission (TRMM) 3A12 and 3B43 data were used to calculate the thunderstorm ratio (β) and total rain accumulation (M_t) of ITU-R P.837-6 for Nigeria [9]. Instead of depending on β and the percentage probability of rain from six-hour temporal resolution data (P_{r6}) to calculate percentage probability of rain in an average year (P_0), the use of TRMM 3A25 and 3B43 data to estimate P_0 and M_t was successfully tested in a few tropical and equatorial sites, particularly in Malaysia [10]. Recently, a combination of TRMM 3B42 and 3B43 had been tested to model one-minute rainfall in Kototabang, West Sumatra, Indonesia [11]. Data with very high spatial resolution (0.1°) such as Global Satellite Mapping of Precipitation (GSMaP) and Global Precipitation Measurement (GPM) were used and the results were validated with rain gauge data at Kototabang [12, 13]. Similar to previous studies based on TRMM data, modified ITU-R P.837-6 using GSMaP and GPM obtained a lower one-minute rainfall rate at Kototabang than the default ITU-R P.837-6.

The ITU released ITU-R P.837-7 in 2017. This model worked based on the average monthly rainfall which obtained from 50 years (1951-2000) of data from the Global Precipitation Climatology Centre (GPCC) Climatology (V 2015) over land and from 36 databases of the European Center of Medium-range Weather Forecast (ECMWF) [8] across the years, 1979-2014, with a spatial resolution of 0.25°, which was five times smaller than the ITU-R P.837-6. Testing this model in Ireland indicated that ITU-R P.837-7 prediction method showed a better performance than ITU-R P.837-6, which overestimated the one-minute rainfall rate [14]. However, the performance of this model had not yet been evaluated in Indonesia, which has climatic region with high rainfall throughout the year. Furthermore, the precipitation significantly varied across the region due to complex topographic conditions [15-18]. Therefore, this study would examine the performance of ITU-R P.837-7 to estimate one-minute rainfall rate in Indonesia. The results would be compared with those estimated by the default ITU-R P.837-6 model, modified ITU-R P.837-6 using 3B42 and 3B43, GSMaP, and GPM. In addition, the use of TRMM 3A25 data would also be evaluated. The results of each model were validated with measurement data at five observation points, namely Kototabang, Padang, Sicincin, Pontianak and Bandung. The number of observation points in this study was larger than previous studies. Recent satellite precipitation measurements showed significant amounts of precipitation concentrated in the coastal regions of Indonesia [19]. The study also qualitatively evaluated the ability of each model to reproduce a rainfall distribution that resembled this pattern.

2. RESEARCH METHOD

One-minute rainfall rate for the desired probability of exceedance ($P(R)_1$) was first estimated using the default ITU-R P.837-6 [1]. Default meant that the input parameter P_0, which was used to calculate $P(R)_1$, was derived from P_{r6}, β, and M_t, which were obtained from ERA-40 data. Subsequently, ITU-R P.837-6 was modified by calculating P_0 and M_t directly using multisensory data, without P_{r6} and β. The value of P_0 was calculated using (1) [10].

$$P_0 = \frac{N_R}{N_T}, \tag{1}$$

where N_R is the number of rainy pixels, and N_T is the number of total pixels. Thus, the modified ITU-R P.837-6 was expressed by (2-4)

$$P(R)_1 = P_0 \exp\left(-1.09R\frac{1+bR}{1+cR}\right) \tag{2}$$

$$b = \frac{M_t}{21797P_0} \tag{3}$$

$$c = 26.02b \tag{4}$$

where R is the rainfall rate for the desired probability of exceedance. The data used to calculate P_0 and M_t are summarized in Table 1. Detailed description of TRMM 3B42, 3B43, 3A25, and GSMaP as well as GPM data could be found in various literatures [20-22]. Finally, the one-minute rainfall rate was calculated using ITU-R P.837-7. All results were then contoured to see the spatial distribution of one-minute rainfall rates.

Table 1. Detailed description of the inputs for the prediction methods

Prediction method	Data to obtain input		Inputs of prediction method		
	Database	Temporal resolution	Parameters	Temporal resolution	Spatial resolution
Default ITU-R P.837-6	ERA-40	6- hour	M_t	annual	1.125° x 1.125°
			P_{r6}		1.125° x 1.125°
			β		1.125° x 1.125°
ITU-R + 3B42 + 3B43	TRMM 3B42	3-hour	P_0	annual	0.25° x 0.25°
	TRMM 3B43	monthly	M_t		0.25° x 0.25°
ITU-R + 3A25 + 3B43	TRMM 3B42	monthly	P_0	annual	0.50° x 0.50°
	TRMM 3B43	monthly	M_t		0.25° x 0.25°
ITU-R + GSMaP	GSMaP	1- hour	P_0	annual	0.10° x 0.10°
			M_t		0.10° x 0.10°
ITU-R + GPM	IMERG	30- minute	P_0	annual	0.10° x 0.10°
			M_t		0.10° x 0.10°
ITU-R P.837-7	GPCC	Monthly	M_t	monthly	0.25° x 0.25°
	ERA-interim		T		0.75° x 0.75°

One-minute rainfall rates from the models were validated using observation data at Kototabang (0.2°S, 100.32°E), Sicincin (0.546°S, 100.3°E), Padang (0.915°S, 100.46°E), Pontianak (0.00°S, 109.37°S), and Bandung (6.9°S, 107.6°E). To adequately estimate one-minute rainfall rate statistics, complete rainfall time series for a given year with one-minute integration time was required. At Kototabang, rainfall rate was measured by Optical Rain Gauge (ORG) and Parsivel disdrometer. Kototabang had the most thorough observation years, during 2014, 2015, 2016, and 2017 using Parsivel and 2003, 2004, 2005, 2008, 2009, 2010, and 2011 using the ORG. Description of ORG and Parsivel observation at Kototabang could be found in some previous studies [16, 23]. Parsivel observation was also used at Padang, but the availability of data from the observation was sparse. Therefore, the data in the literature [24] were used for the validation process. At Sicincin, there were complete observational data from the Parsivel observation during 2018. At Pontianak, observational data existed from 2015-2017, but the complete observational period was only during 2015. Therefore, only data obtained during 2015 were used in the validation process. DBSG3 data [25] were used to validate the model results in Bandung. The data were available during nine years for 0.001 to 5% of time exceeded. The accuracy of the model was evaluated using root–mean–square-error (RMSE) and percentage of errors for each percentage of time exceeded (ε_i) was given by

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(R_{Ei} - R_{Mi})^2}{n}} \tag{5}$$

$$\varepsilon_i = \left(\frac{R_{Ei}-R_{Mi}}{R_{Mi}}\right) * 100 \tag{6}$$

where n is the number of probability levels, R_{Ei} and R_{Mi} are one-minute rainfall rates from the model and measurement, respectively, for a given percentage of time exceeded. Not all locations had simultaneous observation of measurements on the surface and satellites. Therefore, an average one-minute measured rainfall rate was used in the validation process. Moreover, average annual rainfall (M_t) and data denoting average probability to have rain (P_0) were used to calculate one-minute rain fall rates using the modified ITU-R P.837-6. Hence, the annual variation of data was ignored. In this work, the same number of probability levels was used for all locations, so the average RMSE value was calculated without weighting the error with number of observation years and probability levels, which is expressed by (7)

$$\overline{RMSE} = \frac{\sum_{i=1}^{Ns} RMSE_i}{N_s} \tag{7}$$

where RMSE is root mean square error of site i, and N_s is the number of sites (here N_s = 5).

3. RESULTS AND ANALYSIS

3.1. Comparison of prediction and measurement

The first validation point was Kototabang as shown in Figure 1 (a). Kototabang had the most complete observation years, during 2014, 2015, 2016, and 2017 using Parsivel, and 2003, 2004, 2005, 2008, 2009, 2010, and 2011 using the ORG. Average annual rainfall (M_t) based on observations of these instruments was 2601 mm/year. In addition, the data for average probability to have rain (P_0) was 10.28%. The modified ITU-R P.837-6 using TRMM 3A25 + 3B43 showed one-minute rainfall rates which were closest to the observation data, followed by the default ITU-R P.837-6. The ITU-R P.837-7 resulted in smaller rainfall rates than those from the observations and ITU-R P. 837-6, especially when the time percentage exceeded 0.01% and 0.1%, at very small (0.001%) and very large percentages (1%), ITU- R P. 837-7 retrieved a larger rainfall rate. In Sicincin as shown in Figure 1 (b), Padang as shown in Figure 1 (c) and Pontianak as shown in Figure 1 (d), the estimated value was much smaller than the observation data. In Sicincin, the rainfall rate was collected by a Parsivel during 2018. Annual rainfall and the probability having rainfall at this location were 5.388 mm/year and 12.17%, respectively. The distance between Sicincin and Kototabang was only about 62 km, but the annual rainfall at these two locations was very different. In Bandung, the ITU-R P.837-6 shows a good agreement with the observation data as shown in Figure 1 (e).

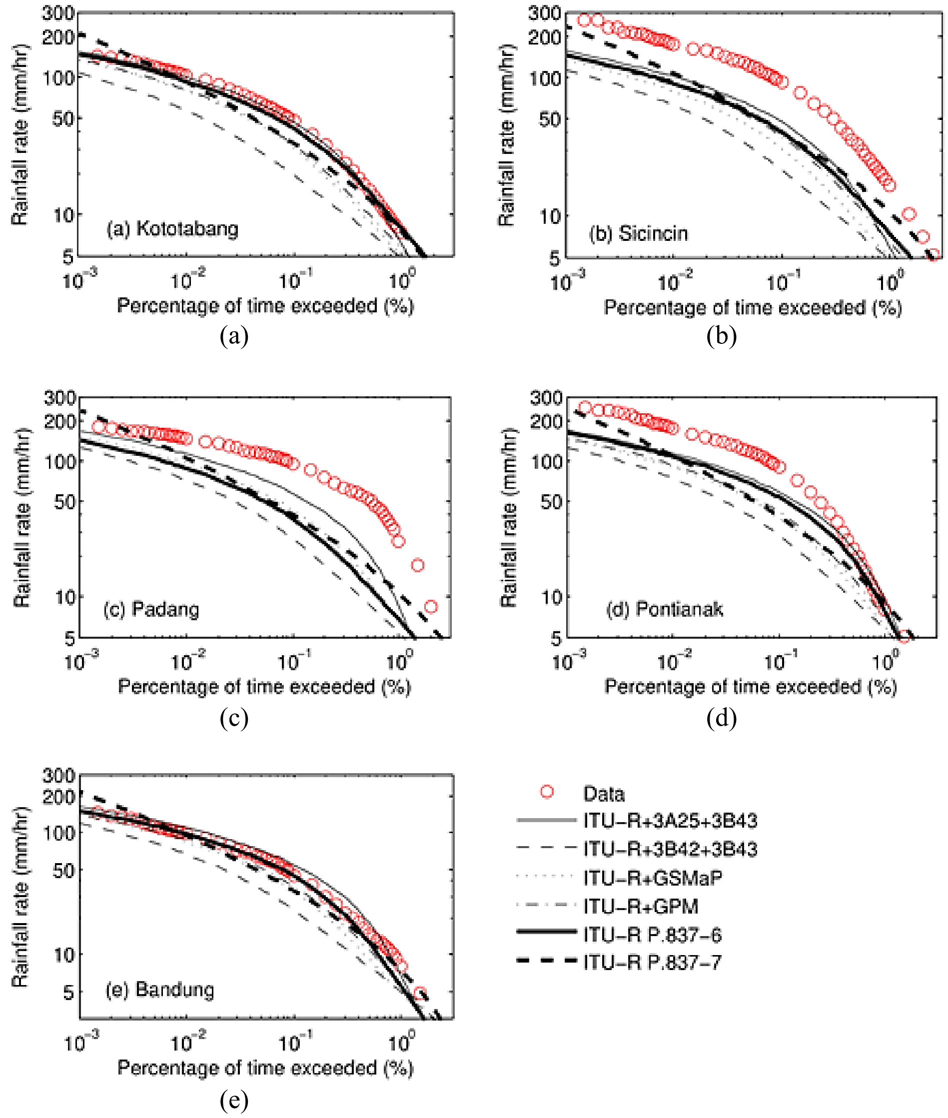

Figure 1. Comparison of cumulative distribution of rainfall rate from measurements and models

The percentage error of each estimation model for Kototabang is given as shown in in Figure 2 (a). Negative values indicated that the models underestimated the rainfall rates. The error percentage for 0.001% of time exceeded from the default ITU-R P.837-6, modified ITU-R P.837-6 using TRMM 3B42+3B43, 3A25+3B43, GSMaP, GPM and ITU-R P.837-7 was -2.41, -29.41, 2.69, -12.35, -11.32 and 38.47, respectively. For 0.01% of time exceeded the values were -9.71, -45.28, -2.92, -23.69, -22.15 and -11.57, correspondingly as shown in Table 2. Therefore, for Kototabang, the modified ITU-R P.837-6 using TRMM 3A25+3B43, and the default ITU-R P.837-6 showed a better performance than ITU-R P.837-7. The performance of ITU-RP.837-7 was better than ITU-R P.837-6 only at large percentages of time exceeded (1%), with an error percentage of 3.35%. The RMSE value between measurement and model results for 0.001% to 5% of time exceeded showed superiority of ITU-R+3A25+3B43 as shown in Table 3.

The percentages of errors for all methods were larger than 30% except when time exceeded at 0.001% for ITU-R P.837-7 (-11.56%). The accuracy of all methods was also low for Padang with error percentages being more than 20%, except when time exceeded at 0.001% for TRMM 3A25+3B43 (-8.88%). Large errors were also found for Pontianak. The Pontianak data were gathered through Parsivel observations done in 2015. Annual rainfall and the probability of having rainfall at this location were 3.235 mm/year and 8.18%, respectively. The error percentage of all methods for Pontianak was also significantly large (> 30%), except when the time percentage was 0.001% for ITU-R P.837-7 (-11%) and for a time percentage of 1% for ITU-R P. 837-6 (-1%). The ITU-R model could not predict rainfall rates accurately at these three locations which was indicated by large RMSE as shown in Table 3.

Table 2. Error percentage (ε_i) between measurement and model results for 0.01% of time exceeded

Prediction method	Error percentage (ε_i) Kototabang	Sicincin	Padang	Pontianak	Bandung
Default ITU-R P.837-6	-9.71	-47.82	-39.60	-38.36	-0.71
ITU-R+TRMM 3A25+3B43	-2.92	-42.08	-22.99	-35.15	11.39
ITU-R+TRMM 3B42+3B43	-45.28	-64.08	-50.52	-57.45	-32.24
ITU-R+GSMaP	-23.69	-54.32	-34.01	-48.65	-14.58
ITU-R+GPM	-22.15	-49.80	-38.92	-46.49	-10.85
ITU-R P.837-7	-11.57	-38.83	-27.39	-38.23	-3.96

The accuracy of ITU-R P.837-6 model was very good for Bandung as shown in Figure 1 (e) and Figure 2 (e). The error percentage of ITU-R P.837-6 was about -1% for 0.001% to 1% of time exceeded. Modification of ITU-R P.837-6 using TRMM 3A25+3B43, GSMaP, and GPM also showed good performance. The ITU-R P.837-7 overestimated the one-minute rainfall rates when time exceeded at 0.001%, with the error percentage of 41.02%. For a larger percentage of time, ITU-R P.837-7 model underestimated rainfall rates with the smallest error percentage of -3.96% at 0.01% of time exceeded. The RMSE showed the superiority of the default ITU-RP.837-6 followed by the ITU-R+3A25+3B43 as shown in Table 3.

Table 3. Root mean square error (RMSE) between measurement and model results for 0.001% to 5% of time exceeded

Prediction method	$RMSE$ Kototabang	Sicincin	Padang	Pontianak	Bandung	$\overline{RMSE}$
Default ITU-R P.837-6	6.37	67.05	49.62	52.59	2.04	35.53
ITU-R+TRMM 3A25+3B43	1.68	59.77	31.89	48.41	8.08	29.97
ITU-R+TRMM 3B42+3B43	32.90	87.68	60.70	77.17	23.77	56.45
ITU-R+GSMaP	17.41	75.70	43.95	66.06	11.73	42.97
ITU-R+GPM	16.11	69.72	48.95	63.19	8.86	41.37
ITU-R P.837-7	14.35	50.57	40.07	47.69	14.07	33.35

Although ITU-R P.837-7 performed worse than ITU-R P.837-6 in Kototabang and Bandung, RMSE of ITU-R P. 837-7 was smaller than ITU-R P.837-6 as shown in Table 3. Therefore, in general, ITU-R P.837-7 exhibited slightly better performance than the default ITU-R P.837-6, consistent with a previous study in Ireland [14]. However, the ITU-R+3A25+3B43 exhibited better performance than ITU-R P.837-7 and default ITU-R P. 837-6. Among the five test sites, the default ITU-R P.837-6 and ITU- R+3A25+3B43 could predict one-minute rainfall rates at two locations accurately, which was indicated by very small RMSE values (< 10), whereas the RMSE values of ITU-R P.837-7 were more than 10 for all locations.

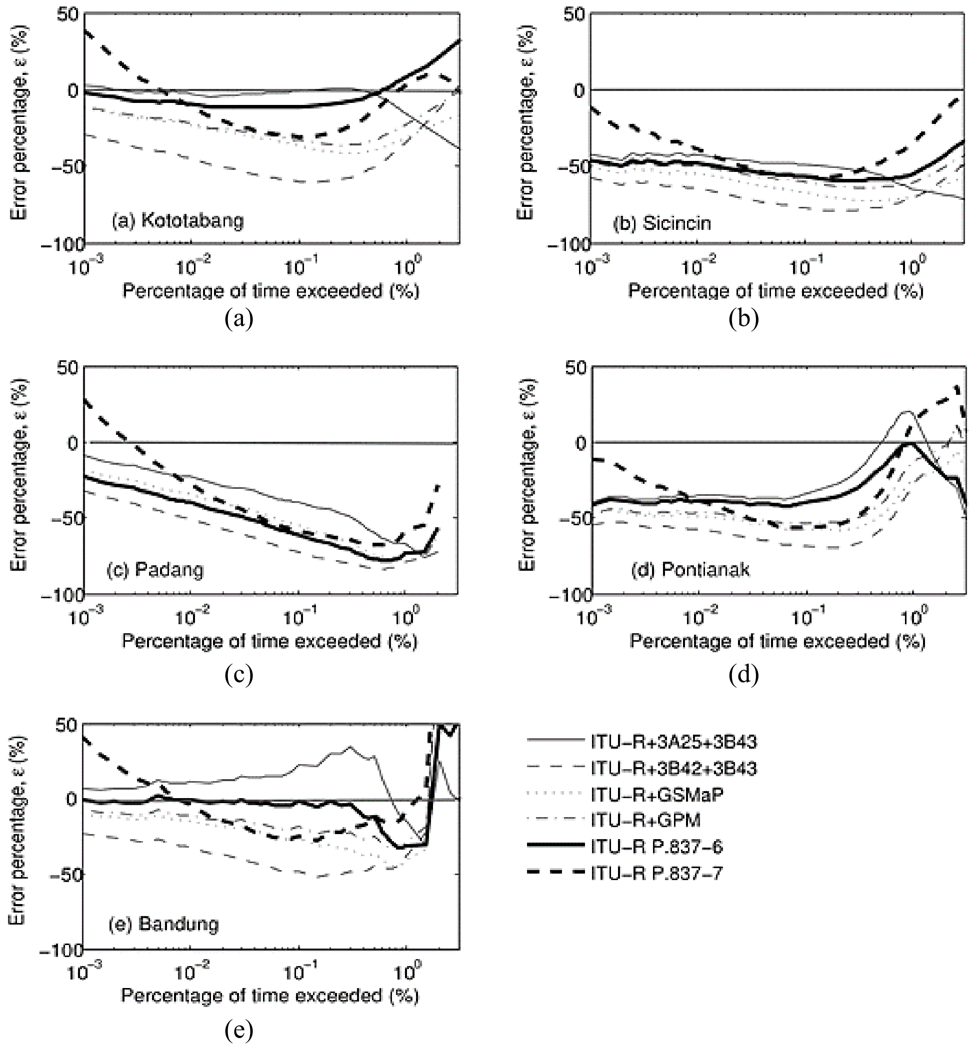

Figure 2. Percentage of errors between measurement and model results for each percentage of time exceeded

3.2. Spatial distribution of one-minute rainfall rates

Figure 3 shows the distribution of one-minute rainfall rates for 0.001% and 0.01% of time exceeded. For the percentage of 0.001%, one-minute rainfall rates estimated by the ITU-R P.837-6 as shown in Figure 3 (a) and modified version of ITU-R P.337 -6 using TRMM 3B42 + 3B43 as shown in Figure 3 (b), 3A25 + 3B43 as shown in Figure 3 (c), GSMaP as shown in Figure 3 (d) and GPM as shown in Figure 3 (e) data were smaller than that estimated by the ITU-R P.837-7 as shown in Figure 3 (f), consistent with Figure 1. This was observed in all Indonesian regions especially over Pacific and Indian Ocean sectors. The highest value of one-minute rainfall rate from the ITU-R P.837-7 (Figure 3 (f)) was 292 mm/h while the highest values obtained by the ITU-R P. 837-6 as shown in Figure 3 (a), modified version of ITU-R P.337-6 using TRMM 3B42+3B43 data asa shown in Figure 3 (b), 3A25+3B43 as shown in Figure 3 (c), GSMaP as shown in Figure 3 (d) and GPM as shown in Figure 3 (e) were 166, 159, 187, 187, and 165 mm/h, respectively. Modified ITU-R P.837-6 using TRMM 3B42 + 3B43 produced the smallest one-minute rainfall rate.

The spatial distribution of one-minute rainfall rate for 0.01% of time exceeded showed a different pattern from that observed at time percentage of 0.001%. ITU-R P.837-7 as shown in Figure 3 (l) and ITU-R P.837-6 as shown in Figure 3 (g) provided maximum values of one-minute rainfall rates, at 130 and 111 mm/h, respectively. In addition, the modified ITU-R P.837-6 using 3A25+3B43 as shown in Figure 3 (i), GSMaP as shown in Figure 3 (j), and GPM as shown in Figure 3 (k) provided maximum rainfall rates of 132, 132 and 110 mm/h, correspondingly. The modified ITU-R P.837-6 using TRMM 3B42 + 3B43 as shown in Figure 3 (h) also gave the smallest one-minute rainfall rate at the time percentage of 0.001%. Although the maximum rainfall rate from ITU-R P.837-7 as shown in Figure 3 (l), 3A25+3B43 as shown in Figure 3 (i), and GSMaP as shown in Figure 3 (j) were almost similar, the spatial distribution of rainfall rate was different. TRMM 3A25+3B43 as shown in Figure 3 (i), GSMaP as shown in Figure 3(j), and GPM provided the highest rainfall rate in coastal areas, which were consistent with the pattern demonstrated by recent satellite precipitation measurements [19]. However, the high-rainfall rate area of ITU-R P.837-7 was broader over the Indian and Pacific Oceans, in addition to coastal area, while ITU-R P.837-6 did not exhibit the highest rainfall rate around coastal areas.

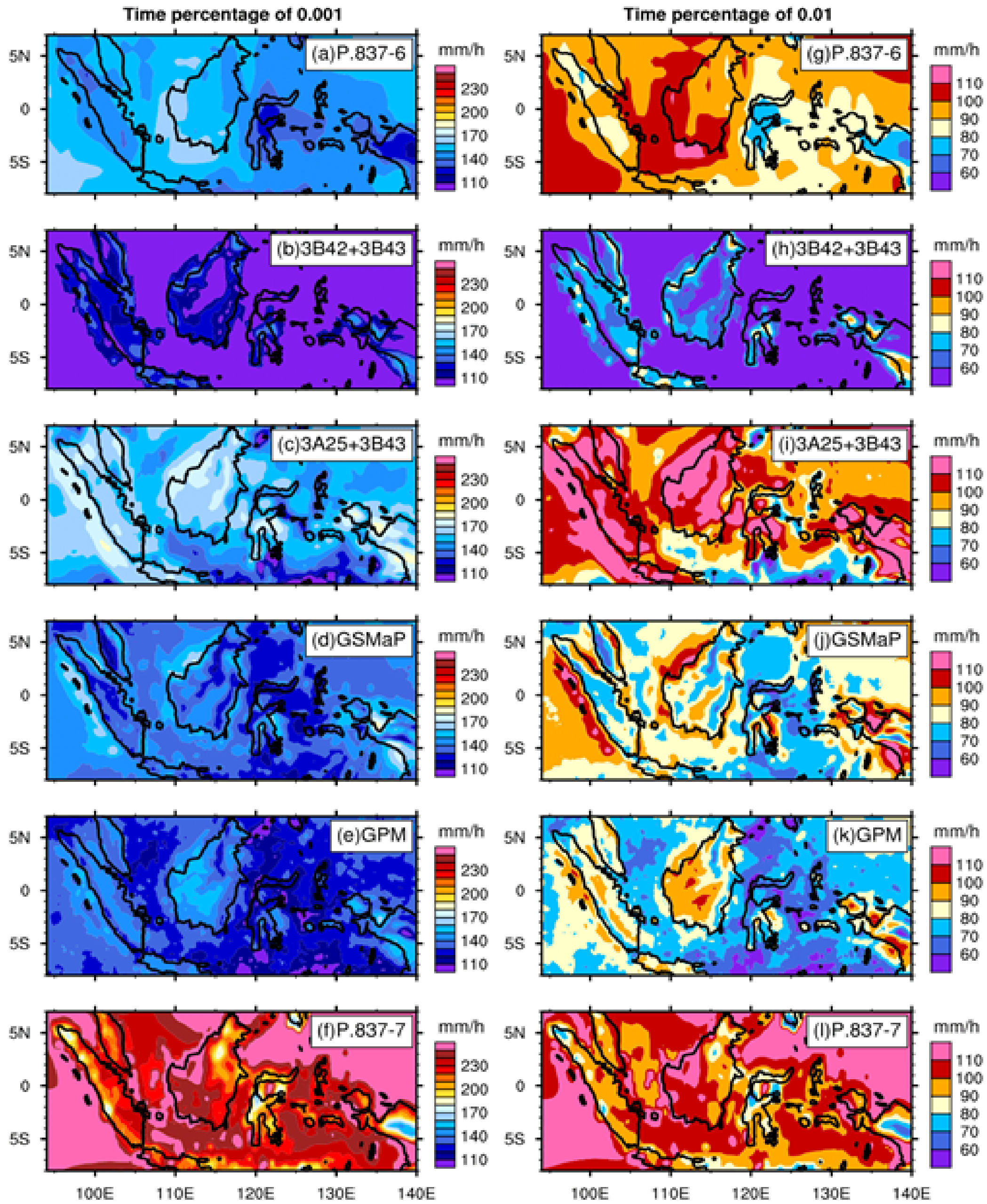

Figure 3. Distribution of rain rate for time percentage of 0.001% (left) and 0.01% (right) estimated by the default ITU-R P.837-6, modified ITU-R P.837-6, and ITU-R P.837-7

For 0.1% and 1% of time exceeded, the modified ITUR P.837-6 using 3A25+3B43, and GSMaP gave larger one-minute rainfall rates than the others as shown in Figure 4, consistent with Figure 1. For 0.1% of time exceeded, the maximum values of rainfall rate obtained by ITU-R P.837-6 as shown in Figure 4 (a), modified ITU-R P.837-6 using TRMM 3B42+3B43 as shown in Figure 4 (b), 3A25+3B43 as shonw in Figure 4 (c), GSMaP as shown in Figure 4 (d), GPM as show in Figure 4 (e), and ITU-R P.837-7 as shown in Figure 4 (f) were 57, 52, 78, 78, 57 and 49 mm/h, respectively. Furthermore, for 1% of time exceeded, the maximum rainfall rates obtained by ITU-R P.837-6 as shown in Figure 4 (g), modified ITU-R P.837-6 using TRMM 3B42+3B43 as shon in

Figure 4 (h), 3A25+3B43 as shown in Figure 4 (i), GSMaP as shown in Figure 4 (j), GPM as shown in Figure 4 (k) and ITU-R P. 837-7 as shown in Figure 4 (l) were 10, 11, 23, 25, 12 and 12, respectively. Therefore, one-minute rainfall rate from ITU-R P.837-7 was slightly larger than that of ITU-R P. 837-6, as found in mainland China [26] and India [27], consistent with Figure 1, but it was smaller than that obtained by TRMM 3A25+3B43.

Regional variations in rainfall were more clearly seen from ITU-R P.837-7 than ITU-R P.837-6, which was due to the smaller resolution of ITU-R P. 837-7's input. Better resolutions of TRMM 3B42+3B43, 3A25+3B43, GSMaP, and GPM also resulted in more obvious regional variation of rainfall rate, than that of default ITU-R P837-6. Calculation of one-minute rainfall rate from ITU-R P.837-7, which involved temperature values, produced a broader high-rainfall intensity area over two warm oceans namely Indian and Pacific Oceans, in addition to being around the coastal area. In terms of similarity of the one-minute rainfall rate distributions with the pattern demonstrated by recent satellite precipitation measurements, the modified ITU-R P.837-6 using TRMM 3A25+3B43 gave the best results. In addition, ITU-R+3A25+3B43 also had the smallest RMSE value, when it was compared to observation data as shown in Figure 3.

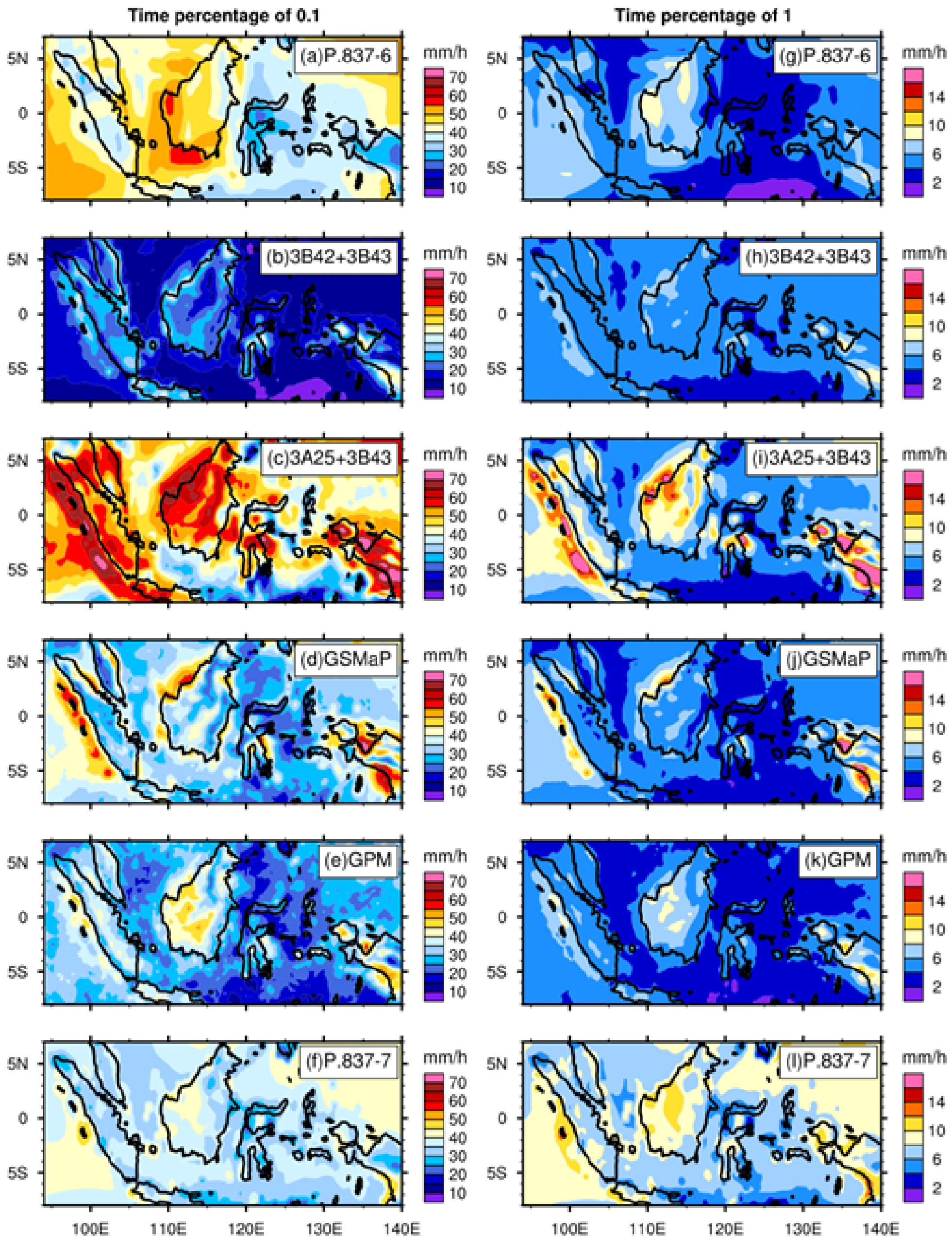

Figure 4. Distribution of rain rate for time percentage of 0.1% (left) and 1% (right) estimated by the default ITU-R P.837-6, modified ITU-R P.837-6, and ITU-R P.837-7

4. CONCLUSION

In general, ITU-R P.837-7 showed a slightly better performance than the default ITU-R P.837-6 in estimating one-minute rainfall rates in Indonesia, which was indicated by a smaller average root mean square error. Among five test sites, the ITU-R models showed good performance at two locations, namely Kototabang and Bandung. From these two locations, one-minute rainfall rate retrieved by ITU-R P.837-6 was very similar to the observation data. The error percentage of ITU-R P.837-7 was smaller at large (1%) and small (0.001%) percentages of time exceeded, at which this model produced a larger one-minute rainfall rate than the observation data. Although the error percentage of ITU-R P.837-7 at some locations was larger than that of ITU-R P. 837-6, the spatial distribution of rainfall produced by this model was closer to the pattern demonstrated by recent satellite precipitation measurements, in which significant amounts of precipitation concentrated in the coastal region of Indonesia. However, calculation of one-minute rainfall rate from ITU-R P.837-7, which used temperature values, produced a broader high-rainfall intensity area, over two warm oceans namely Indian and Pacific Oceans, in addition to being around the coastal area. Modification of ITU-R P.837-6 using the TRMM 3A25 and 3B43 data, provided one-minute rainfall rates, which could compete with those derived from the default ITU-R P.837-6 and ITU-R P.837-7. In terms of the similarity of one-minute rainfall rate distribution with the pattern demonstrated by recent satellite precipitation measurements, the modified ITU-R P.837-6 using TRMM 3A25+3B43 gave the best results. Furthermore, TRMM 3A25+3B43 also had the smallest RMSE value when it was compared with observation data. Finally, the results of this study indicated that the ITU-R model could not accurately predict one-minute rainfall rates at all locations. Therefore, more efforts would have to be devoted to improve this model.

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