

PREDICTION OF MONTHLY RAINFALL BASED ON THE TRMM PRECIPITATION RADAR SATELLITE DATA OVER REGION OF INDONESIA

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ABSTRAK

Kepulauan Indonesia merupakan wilayah yang mendapatkan curah hujan sepanjang tahun, namun jaringan stasiun pengukuran curah hujan di wilayah ini tidak sepadat atau sebanyak seperti di benua besar lainnya. Oleh karena itu, satelit pengamatan curah hujan merupakan solusi terbaik untuk pengamatan dengan cakupan temporal dan spasial yang memadai. Tujuan dari penelitian ini adalah untuk validasi dan prediksi curah hujan bulanan berdasarkan data satelit *Tropical Rainfall Measuring Mission Precipitation Radar (TRMM PR)*. Data yang digunakan adalah curah hujan bulanan dari satelit *TRMM PR Level3A25* dan *in situ* data dari BMKG selama periode tahun 2004 - 2008. Hasil validasi menunjukkan bahwa data satelit memberikan nilai lebih rendah dari data observasi, kecuali di wilayah anti-monsunal (C) dimana data satelit memberikan nilai lebih besar dari data observasi. Pola time series rata-rata hujan bulanan berdasarkan 39 lokasi selama periode lima tahun (2004-2008) menunjukkan pola yang sangat mirip dengan data observasi, dengan memberikan nilai korelasi yang tinggi ($r = 0,82-0,98$) dan *RMSE (Root Mean Squared Error)* kurang dari 50 (mm/bulan). Hasil prediksi curah hujan bulanan dengan menggunakan metode *ARIMA (Autoregressive integrated moving average)* menunjukkan nilai yang lebih besar dari data observasinya dan pola curah hujan bulannya untuk periode satu tahun (Januari-Desember 2009) memiliki pola kemiripan dengan data observasi.

Kata kunci: prediksi, hujan, Tropical Rainfall Measuring Mission Precipitation Radar (TRMM PR), ARIMA (Autoregressive integrated moving average)

INTRODUCTION

The Indonesian archipelago is characterized as a huge amount of 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 the global rainfall is necessary for the study of climatology, the prediction of flood and the problem of water resource.

In general, rain gauge observations yield relatively accurate point measurements of rainfall but also suffer from sampling error in representation areas means. Also, they are not available over most oceanic and undeveloped land areas (Xie and Arkin, 1996). Measured data from rain gauge networks are still conventionally the most reliable source of area averaged rainfall for the land surface of the earth. However, rain gauge measurement networks at Indonesian archipelago are not as dense or regular as in other major continent. Therefore, satellite observations of rainfall are the best solution for adequate temporal and spatial coverage. Moreover, the result of satellite observation combined with the observation data inland and oceanic is so important (Huffman *et al.*, 1995).

Satellite observations have an advantage over radar and rain gauge data because of their global spatial coverage. However, the relationship between satellite-

measured radiances and rainfall reaching the ground is difficult to determine, so it is important to quantify the magnitudes of errors of the satellite estimates (McCollum, *et al.*, 2002). Satellite-based precipitation products could provide very high temporal (3 hourly) and spatial (0.5° latitude x 0.5° longitude grid size) resolution. Nevertheless, they are subject to larger biases and stochastic errors and need to be adjusted to *in situ* observations (Barret *et al.*, 1994; Rudolf *et al.*, 1996).

The Tropical Rainfall Measuring Mission (TRMM) is a joint mission between US and Japan, and it is the first satellite earth observation mission to monitor tropical rainfall, which closely influences to global climate and environment change. The main objective satellite was to provide a better understanding of precipitation structure and heating in the tropical regions of the earth (Simpson *et al.*, 1996). Short and North (1990) and Shin *et al.* (2000) noted that one of the advantage of TRMM is be that sampling errors and related biases (e.g, beam filling errors) can be reduced by its low latitude (350 km) and low inclination (35°). A comparison of a 2-year (1998 and 1999) monthly rainfall data derived from the TMI, PR, TRMM combined algorithm, and TMI emission algorithm were carried out by Shin *et al.* (2001). The results showed that for the global and zonal means, the TMI rain rates were the largest and TRMM PR estimates were the lowest.

Aldrian and Susanto (2003) made the distribution pattern of rainfall in the Indonesian region with multiple correlation method, where Indonesian rainfall area is divided into 3 areas, namely the region Monsoonal Type (A), Semi-Monsoonal type (B) and region anti-monsoonal type (C). Region A has one peak and one valley rainfall and influenced by two monsoon systems of the Northwest Monsoon (wet seasons) from November to March (NDJFM) and the Southeast Monsoon (dry seasons) from May to September (MJJAS). Area B has two peaks of rainfall in October-November (ON) and March-May (MAM). Area C has one peak and one valley rainfall, namely June-July and November-February (NDJF)

In this work, attempts have been made to compare the rainfall determined by TRMM PR products with the values of ground-based rain gauge over Indonesia. The aim of this research are : (1) To evaluate the validation of monthly rainfall over region of Indonesia based on the TRMM PR satellite data and develop a prediction of monthly rainfall; (2) To evaluate the accuracy of prediction of monthly rainfall over region of Indonesia based on the TRMM PR satellite data.

RESEARCH METHODS

The research location was the Indonesia archipelago. It was located in 92.50°E – 141.20°E and 8.14°N – 12.0°S (Figure1). Distribution of research locations were 27 stations, located in parts of Indonesia which covers the monsoonal types(A) (Jakarta, Bogor, Bandung, Jatiwangi, Cilacap, Tegal, Semarang, Surabaya, Kalianget, Denpasar, Ampenan, Kupang, Manado, Ujungpandang, Balikpapan, Samarinda, Banjarmasin, Palangkaraya, Biak, Wamena, Jayapura, Merauke, Jambi, Palembang, Bengkulu, and Lampung), 7 stations located at the semi-monsoonal types(B) (Tarakan, Sintang, Pontianak, Banda Aceh, Medan, Pekanbaru, and Padang) and 5 stations located at an-

ti-monsoonal types(C) (Ambon, Ternate, Gorontalo, Palu, and Kendari).

With material used are monthly rainfall derived from Satellite TRMM PR Level3A25 and in situ data from rain gauge measurement by BMKG in 2004 to 2008.

Three types of analysis conducted on monthly rainfall data, that is; point by point analysis, time series average of all point, and monthly average of all point. Statistical routines could be used to analyze the relationship of the TRMM product to rain gauge data. The measures of the closeness of the satellite estimates to the observed values were the linear correlation coefficient (r), mean bias error (MBE) and the root mean square error (RMSE) defined as follows (Feidas, 2010):

$$r = \frac{\sum_{i=1}^n (S_i - \bar{S})(G_i - \bar{G})}{(n-1) \sigma_S \sigma_G} \tag{1}$$

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

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

Where S_i are the estimated values, G_i are the reference gauge values, σ_S and σ_G are their standard deviations, and n the number of data pairs

This analysis is performed to determine the relationship between monthly rainfall from satellite TRMM PR and in-situ data. With the correlation analysis can identify how the validity of rainfall data from satellite TRMM PR. The RMSE is used to find out how much the average error value between the data from satellite TRMM PR and in-situ data. Mean bias error (MBE) is a good measure of model bias and is simply the average of all differences in the set.

Furthermore, ARIMA method was used to prediction of monthly rainfall over region of Indonesia.



Figure 1. Research Location

ARIMA (Autoregressive Integrated Moving Average) model introduced by Box and Jenkins (1976) includes autoregressive as well as moving average parameters, and explicitly includes differencing in the formulation of the model. Specifically, the three types of parameters in the model are: the autoregressive parameters (p), the number of differencing passes (d), and moving average parameters (q). Autoregressive process (p) can be expressed by the equation:

$$Y_t = \mu + \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \dots + \phi_p Y_{t-p} + e_t \quad (4)$$

Moving average process (q) can be expressed by the equation:

$$Y_t = \mu + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \dots - \theta_q e_{t-q} \quad (5)$$

Where Y_t is dependent variable, $Y_{t-1} Y_{t-2} \dots Y_{t-p}$ and $e_{t-1} e_{t-2} \dots e_{t-q}$ are independent variables, μ is the constants, $\phi_1 \phi_2 \dots \phi_p$ are autoregressive coefficient, $\theta_1 \theta_2 \dots \theta_q$ are moving average coefficient, e_t and e_{t-q} are error value

RESULTS AND DISCUSSIONS

In the monsoonal type, the time series of monthly rainfall relationship showed 17 point gauges ($r=0.51-0.73$) and 10 point gauges in low correlation ($r=0.11-0.33$), and RMSE based on 27 point gauges were more than 100 (mm/month). The average time series of monthly rainfall from TRMM PR3A25 was very slightly than monthly gauge data, where the average time series monthly rainfall were 170.0 (mm/month) and 170.1 (mm/month), respectively. The pattern of average time series monthly rainfall was quite similar with gauge data, and the coefficient correlation was high correlation ($r=0.94$), and RMSE was 35.1 (mm/month) (Figure 2a). Meanwhile, monthly average rainfall pattern of TRMM PR showed very good agreement with the ground reference giving high correlation ($r=0.98$) and RMSE was 19.9 mm/month (Figure 2b).

In the semi-monsoonal type, time series of monthly rainfall point by point relationship showed two point gauges in medium correlation ($r=0.51-0.52$) and five point gauges in low correlation ($r=0.12-0.29$), and generally, RMSE based on seven point gauges were more than 100 (mm/month). The average time series of monthly rainfall from TRMM PR3A25 was slightly than monthly gauge data, where the average time series monthly rainfall were 199.9 (mm/month) and 213.0 (mm/month), respectively. The pattern of average time series monthly rainfall was similar to gauge data and the coefficient correlation was medium correlation ($r=0.59$) and RMSE was 76.4 mm/month (Figure 3a). Furthermore, the monthly average rainfall pattern of TRMM PR data showed very good agreement with the ground reference data ($r=0.82$) and RMSE was 33.5 (mm/month) (Figure 3b).

In anti-monsoonal type, time series of monthly rainfall point by point relationship showed 2 location gauges in medium correlation ($r=0.47-0.58$) and 3 location gauges in low correlation ($r=0.11-0.33$), and RMSE were more than 100 (mm/month). The average time series of monthly rainfall from TRMM PR was greater than monthly gauge data, where the average time series monthly rainfall were 163.9 (mm/month) and 148.28 (mm/month), respectively. The figure indicated the pattern of average time series monthly rainfall was similar to gauge data and the coefficient correlation was in medium correlation ($r=0.63$) and RMSE was 80.8 (mm/month) (Figure 4a). The monthly average rainfall pattern of TRMM PR data showed very good agreement with the ground reference data ($r=0.87$) and RMSE was 32.9 mm/month (Figure 4b).

The results of prediction monthly rainfall by ARIMA method showed an overestimated condition (28.8% in monsoonal type, 43.6% in semi-monsoonal type, and 76.1% in anti-monsoonal type). The coefficient correlation of prediction monthly rainfall point by point based on rain gauge data (period 2004 to 2008) in monsoonal type (A) were 5 location in low ($r=0.32$ to 0.43), 15 location in medium ($r=0.51$ to 0.68), and 7 location in high ($r=0.78$ to 0.87), while the correlation of prediction monthly rainfall based on TRMM PR data were 11 location in low correlation, 8 location in medium correlation, and 8 location in high. And in general, the value of RMSE were 50 to 150 (mm/month). The coefficient correlation of monthly rainfall average was 0.97 (rain gauge) and 0.95 (TRMM PR3A25) with RMSE were 19.7 (rain gauge) and 16.0 (TRMM PR3A25) (Figure 5a).

Furthermore, in the semi-monsoonal type (B), the coefficient correlation of prediction monthly rainfall based on rain gauge data (period 2004 to 2008) were 4 location in low ($r=0.11$ to 0.33), and 3 location in medium ($r=0.51$ to 0.70), while the correlation of prediction monthly rainfall based on TRMM PR data were 6 location in low ($r=0.01-0.43$), and 1 location in medium correlation ($r=0.7$). RMSE were 50 to 150 (mm/month). The coefficient correlation of monthly rainfall average were 0.65 (rain gauge) and 0.60 (TRMM PR3A25) with RMSE were 46.5 (mm/month) (rain gauge) and 88.5 (mm/month) (TRMM PR3A25) (Figure 5b).

In the anti-monsoonal type (C), the coefficient correlation of prediction monthly rainfall based on rain gauge data (period 2004 to 2008) were 3 location in low ($r=0.19$ to 0.29), and 2 location in medium ($r=0.55$ and 0.61), while the correlation of prediction monthly rainfall based on TRMM PR data were 4 location in low ($r=0.14-0.28$), and 1 location in medium correlation ($r=0.61$). And generally, RMSE were 50 to 100 (mm/month). The coefficient correlation of

monthly rainfall average were 0.18 (rain gauge) and 0.28 (TRMM PR3A25) with RMSE were 64.5 (rain gauge) and 60.1 (TRMM PR3A25)(Figure5c).

The distribution of monthly rainfall by satellite data showed an underestimated condition in monsoonal type and semi-monsoonal type. It was evident from the negative bias error, where the MBE were -32.5% and -45.7%, respectively. Meanwhile, in anti-monsoonal type showed an overestimated condition, the MBE was 27.19%. As-syakur, *et al.*, (2010) also showed that the value TRMM product was underestimated than

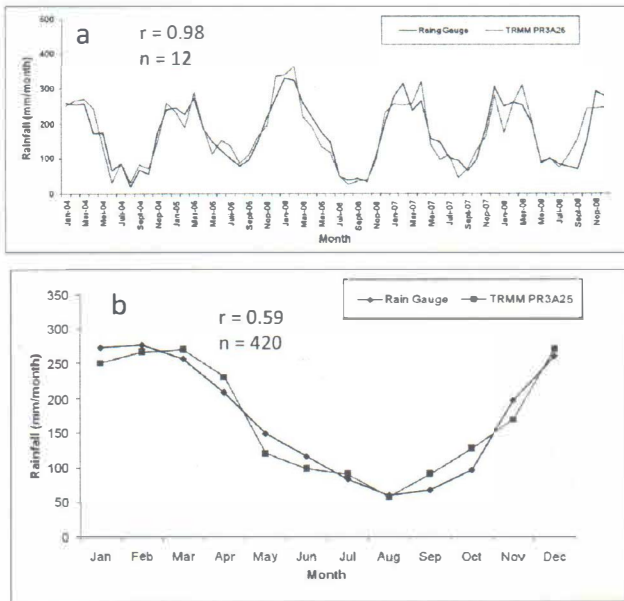


Figure 2 a) Average time series monthly rainfall and b) Monthly average rainfall pattern by TRMM PR and rain gauge (period 2004-2008) in Monsoonal Type (A).

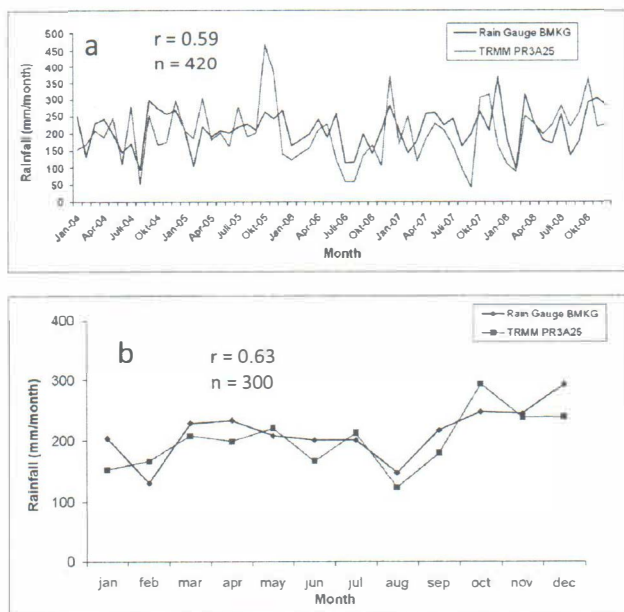


Figure 3 a) Average time series monthly rainfall b) Monthly average rainfall pattern by TRMM PR and rain gauge (period 2004-2008) in Semi-Monsoonal Type (B)

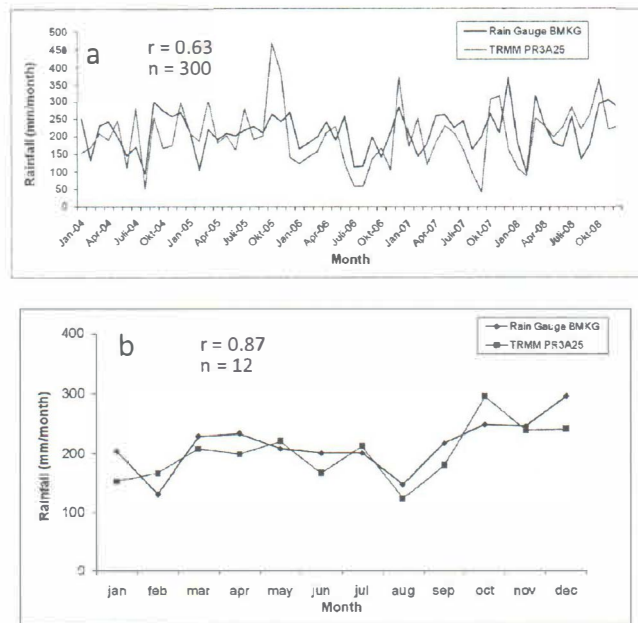


Figure 4 a) Average time series monthly rainfall b) Monthly average rainfall pattern by TRMM PR and rain gauge (period 2004-2008) in Anti-Monsoonal Type (C)

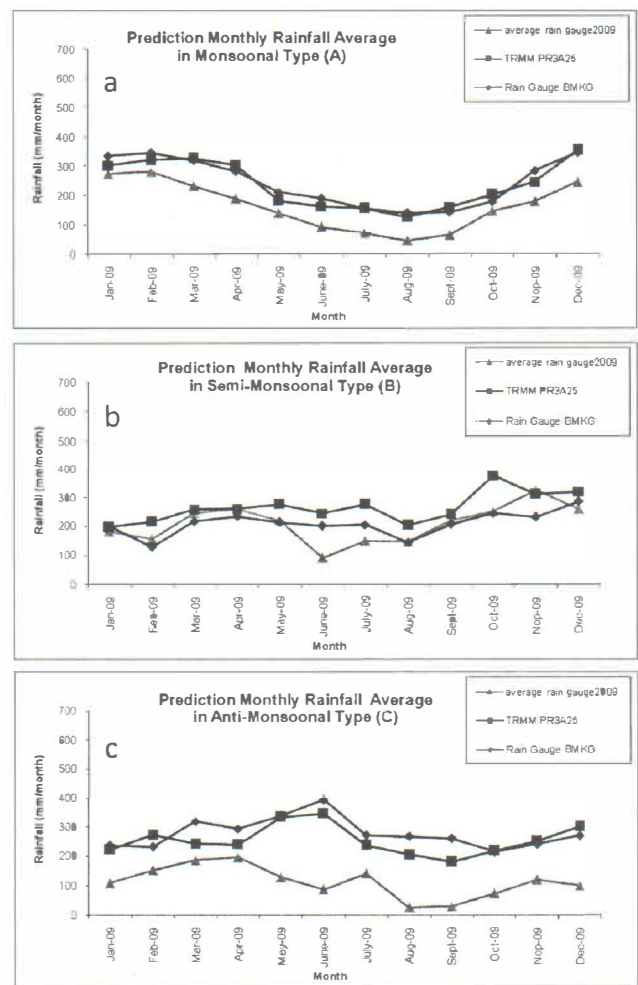


Figure 5 Prediction of monthly average rainfall pattern by TRMM PR and rain gauge (period January-December 2009) a) in Monsoonal type b) in Semi-monsoonal type c) in Anti-Monsoonal type

monthly gauge data over Bali Island. Islam and Uyeda (2007) also showed that the TRMM products underestimated rainfall during monsoon in the heavy rainfall regions of Bangladesh.

The pattern of average time series monthly rainfall was similar to gauge data. This situation indicates TRMM PR3A25 products can be used to determine monthly climatic characteristics. The relationships of the monthly average rainfall measured by TRMM PR3A25 and rain gauge showed very good agreement with the ground reference giving high correlation ($r=0.82-0.98$) and RMSE was less than 50 (mm/month). The pattern of monthly rainfall between TRMM PR and rain gauge data was quite similar which indicate that TRMM PR3A25 can be used to find rainfall patterns in the locations that do not have a rain gauge.

The pattern of prediction monthly average rainfall measured by TRMM PR and rain gauge were similar to gauge data, and the relationships showed high correlation (in monsoonal type), medium correlation (in semi-monsoonal type), and low correlation (in anti-monsoonal type). Arief *et al.*, (2008) also showed that the result of prediction monthly rainfall by ARIMA method based on TRMM 3B43 data were in high correlation in Jakarta ($r=0.77$) and medium correlation in Pontianak ($r=0.49$).

CONCLUSIONS AND SUGGESTION

The TRMM PR3A25 data showed an underestimated condition than the gauge data in the monsoonal and semi-monsoonal type while in the anti-monsoonal type showed the satellite gave an overestimated condition. The validation of monthly rainfall by satellite showed very good agreement with gauge data over Indonesian, on monthly average rainfall. On the other hand, low-medium correlation was shown in the results of point by point. This indicates that point by point analysis is poorly to be adequately served as a stand-alone monthly climate product. Meanwhile, if the TRMM PR3A25 data are used to cover large areas by averaging, this product is capable to estimate variability of monthly rainfall.

The quality of the satellite rainfall measurements needs to be evaluated continually. Further studies require be validating on seasonal and annual timescales, and also comparing with the TRMM PR3B43 product.

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