Accuracy Assessment of Global Satellite Mapping of Precipitation (GSMaP) Product Over Indonesian Maritime Continent

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ABSTRACT

Precipitation is the key factor of energy and water cycle of the earth. The aim of the research is to evaluate the accuracy of GSMaP (Global Satellite Mapping of Precipitation) by using the rain-gauged precipitation measurement across Indonesian Maritime Continent at daily scale. We compare the daily rainfall precipitation of GSMaP with 152 rain-gauge observation stations during 2016. The results show that GSMaP products generally over-estimated precipitation amount with the average accuracy is 82.6%. The performance of precipitation estimation based on satellite data is poorer in mountainous area than in flatlands. According to location, Moluccas and Papua Island have the highest mean correlation (0.40 – 0.61). Meanwhile, the lowest is in small islands such as Bali and Nusa Tenggara (0.20 – 0.47). The highest monthly average correlation is in January while the lowest is in June. The results also show that the daily mean errors (ME) is 0.16 and the root mean square errors (RMSE) is 17.44. However, from the results indicate that GSMaP algorithm is a good performance to estimate rainfall in the area.

Keywords: GSMaP, precipitation, rain-gauged
1. Introduction

Precipitation is a main factor of water and energy cycle of the earth, and is also an important input for land surface and hydrological models [Gottschalck, et al 2005]. Accurate precipitation measurement on regional or global scale are very important for understanding the climate and hydrological cycle. Rain-gauges provide a direct physical measurement of precipitation. However, rainfall monitoring at ground stations are too sparse to achieve the coverage needed for accurate patterns, especially as spatial variability [Verninmen, 2012].

Because of the limitations of ground-based observation in spatial coverage, satellite derived rainfall data have been developed in last two decades [Soooroshian, 2000; Kidd, 2003; Joyce, 2004; Turk, 2005; Huffman, 2007; Aonashi, 2009]. Global Satellite Mapping of Precipitation (GSMaP) is a project initiated by Japan Science and Technology Agency (JST) in 2002 and has been promoted by the Japan Aerospace Exploration Agency (JAXA) Precipitation Measuring Mission (PMM) since 2007 to produce a global precipitation product with high temporal and spatial resolution [Ushio, 2009]. However, the data still involve uncertainties with inhomogeneous patterns over diverse regions due to the indirect nature of satellite measurements, influenced by inaccuracies in cloud top reflectance, thermal radiance and infrequent satellite overpasses [AghaKouchak, 2009]. A lot of studies have evaluated satellite-derived precipitation over area of interest by comparing to rain gauge rainfall data [Promasakha, 2013; Setiawati, 2016].

The aim of this study is to evaluate the accuracy of GSMaP by using the rain-gauge based precipitation over Indonesian Maritime Continent. Indonesian maritime continent consists of more than 17,000 small islands with five large islands (Sumatera, Java, Kalimantan, Sulawesi and Papua) with many high mountains. It is located in tropical region, from 6°N-11°S and 90°E-141°E. The climate of Indonesia is influenced by global atmospheric scale such as ENSO
[Giannini, 2007], regional scale such as monsoon [Moron, 2009] which has inter-annual variability and local scale such as land-sea breeze and mountain-valley breeze [Moron, 2010].

2. Data and Methodology

2.1. GSMaP Rainfall Data

The GSMaP project started in 2002 with purposes of development of rainfall rate retrieval algorithm and production of high resolution global precipitation maps from satellite data [Ushio, et al, 2009]. Major inputs to GSMaP are observations from geostationary satellite data such as MTSAT, METEOSAT-7/-8 and GOES -11/-12 and from Low earth orbit satellite data such as TRMM, GPM Core, AQUA and DMSP. GSMaP covers quasi global (60°N-60°S) with horizontal grid spacing of 0.1 degree (3600x1200 pixels) and one hour interval. The GSMaP_NRT Ver.6 is used for the period from January until December 2016.

2.2 Rain gauge observation data

To assess the uncertainties of GSMaP precipitation estimations, daily observed rainfall data from 152 stations network of BMKG (Badan Meteorologi Klimatologi dan Geofisika), the Indonesian government met agency, were used as reference data to validate GSMaP_NRT estimation. See Fig.1.

Fig 1. Rain-gauge Networks
2.3 Validation Method

In this study, several widely used statistical metrics (Table 1) to quantitatively evaluate the performance of GSMaP_NRT precipitation products. The standard comparison method for estimating rainfall involve computation are following:

a. Coefficient Correlation (CC) also called Pearson’s product moment correlations. The coefficient correlation is a measure of the strength and the direction of the linear relationship between two variables. The correlation coefficient may take any value between -1.0 and +1.0

b. Mean Error (ME) is an informal term that usually refers to the average of all the error in a set. An “error” in this context is an uncertainty in a measurement, or the difference between the measured value and true/correct value. The range of ME is 0 to infinity and the perfect score is 0.

c. Mean Absolute Error (MAE) measures the average of the absolute deviation between the estimations and observations. Absolute error retains the differences in magnitude that would otherwise be reduced because positive and negative differences would cancel each other to some degree. The range of MAE is 0 to infinity and the perfect score is 0.

d. Root Mean Square Error (RMSE) is similar to MAE, measure the mean error magnitude, only it gives greater weight to the larger error because the differences are square before adding. The range of RMSE is 0 to infinity and the perfect score is 0.
Table 1. List of the statistical metric used in the statistical evaluation

| Statistic Metric                  | Equation                                                                 | Perfect Value |
|----------------------------------|--------------------------------------------------------------------------|---------------|
| **Correlation Coefficient (CC)** | $CC = \frac{1}{N} \sum_{n=1}^{N} (f_n - \bar{f})(r_n - \bar{r})}{\sigma_f \sigma_r}$ | 1             |
| **Mean Error (ME)**              | $ME = \frac{1}{N} \sum_{n=1}^{N} (f_n - r_n)$                           | 0             |
| **Mean Absolute Error (MAE)**    | $MAE = \frac{1}{N} \sum_{n=1}^{N} |f_n - r_n|$                     | 0             |
| **Root Mean Square Error (RMSE)**| $RMSE = \sqrt{\frac{1}{N} \sum_{n=1}^{N} (f_n - r_n)^2}$                 | 0             |

Notes: n = number of samples; $f_n$ = a test field of $f$ representing a satellite precipitation estimate; $r_n$ = a reference field $r$ that stands for precipitation gauge values.

3. Results and Discussion

3.1 Validation of Daily Precipitation

The relationship between estimated daily precipitations from meteorological satellite data to rain-gauge were investigated by statistics parameter. Fig 2. Shows some example of comparison between daily GSMaP rainfalls versus rain-gauge data at five large islands. The highest relationship between both the data in five large islands showed that the linear regression of $R^2$ was 0.4386 at Cutbau-Sumatera, 0.3343 at Perak 1 in Java, 0.2972 at Sepinggan-Kalimantan, 0.362 at Gorontalo-Sulawesi, 0.3763 at Merauke-Papua-Mollucas and 0.2696 at Malikalabahi-Nusa Tenggara.

The average value of CC is 0.39 with the highest is 0.66 in Cutbau-Sumatra and the lowest is -0.02 in Kalianget, Java. While the value of RMSE is from 8.5 at Lasiana-Nusa Tenggara until 36.6 at Cilacap-Java with average value of 17.4, so that the mean accuracy of GSMaP NRT for daily rainfall estimation is 82.6%. Moreover, the values of ME vary from -8.2 at Ruteng-Nusa Tenggara to 6.1 at Serui-Papua&Mollucas with the average value of 0.09. While
the value of MAE is from 0.01 to 0.04, which 16.2% of stations have daily MAE of 0.01, 43.2% of stations have value 0.02, 35.8% of stations have value 0.03 and only 4.7% of stations 0.04. It mean that the average of the absolute deviation between the estimations and observations is near to zero.

Fig 2. Relation of daily GSMaP_NRT to observation at (a) Cut Bau-Sumatra (b) Perak1-Java (c) Sepinggan-Kalimantan (d) Gorontalo-Sulawesi (e) Merauke-Papua&Mollucas (f) Malikalabahi-Nusa Tenggara for daily scale during January-December 2016
3.2 Validation of GSMaP in the five Big Islands

Based on the islands, the highest value of CC is 0.44 in the eastern part of Indonesia (Papua & Mollucas Islands), then followed by Sumatra and Kalimantan with the value of 0.41, Sulawesi and Java are 0.36 and the lowest value of CC is in Bali-Nusa Tenggara Islands. On the contrary, the lowest average of RMSE is 13.7 in Bali-Nusa Tenggara Islands, followed by Papua & Mollucas, Sulawesi, Java and the highest is in Sumatra and Kalimantan with value of 18.5. The value of ME that the closest to zero is in Kalimantan -0.1 which under-estimated from observation, followed by Papua & Mollucas of 0.3 (over-estimated), Sulawesi is -0.6 (under-estimated), Java is 0.6 (over-estimated), Sumatra is 0.8 (over-estimated) and Bali-Nusa Tenggara is -1.2 (under-estimated). Meanwhile, the value of MAE for five big island are almost same between 0.01 (Sulawesi, Bali-Nusa Tenggara and Papua & Moluccas) until 0.02 (Sumatera, Java and Kalimantan).

3.3 Validation of GSMaP per months

![Fig. 3 Monthly mean of (a) ME and RMSE (b) CC and MAE](image)

The monthly value of CC, RMSE ME and MAE are showed in Figure 3. The best accuracy according to RMSE is 10.4 in August, but the worst is 19.0 in November. Moreover, the highest ME is 2.24 in November and over-estimated from rain-gauged data, while the lowest ME
is -0.34 in March as seen on Fig. 3(a). The highest values of CC is 0.49 in January while the lowest is 0.27 in June. Moreover, MAE value has highest in November of 0.36 and has the lowest in August of 0.15 as seen on Fig. 3(b).

3.4 Validation of All Indonesia

![Maps showing validation of all Indonesia](image)

Fig. 4 Yearly mean of (a) CC (b) MAE (c) ME (d) RMSE ) of all Indonesia

Generally, over the year 2016, the value of CC in Indonesia are between 0.25-0.5 (green dot), except in Aceh and West Sumatera, Molucca, and some places in Kalimantan and Sulawesi,
have thee value are more than 0.5 (purple dot). Otherwise, the value of CC is under 0.25 for some places in Java, Bali-Nusa Tenggara and Sulawesi (red dot), see Fig. (4a).

The value of MAE is under 0.01 for Bali-Nusa Tenggara, Sulawesi and Molucca (purple dot). Meanwhile, the value of MAE between 0.01-0.02 are commonly distributed in eastern part of Sumatera until Lampung, Banten, West Nusa Tenggara, east Kalimantan, Molucca & Papua (green dot). Otherwise, The value MAE >0.02 are also distributed in Sumatera, Java, Kalimantan and Papua (red dot), see Fig. (4b).

The distribution of bias in Indonesia according to ME value shows underestimated which notified with the negative value of ME between -5.0 – 0.0 in some part in Sumatera, Java, Kalimantan, Bali-Nusa Tenggara, most part of Sulawesi and Molucca (green dot). While overestimate result with ME value between 0-5.0 for Sumatera, Java, Kalimantan and Sulawesi (brown dot) and the value of ME is > 5.0 for some places in Java, Sumatera and Papua (red dot), see Fig (4.c).

The value of RMSE are between 0-15 in Sumatera, Java, most of Bali-Nusa Tenggara, Central Sulawesi and Molucca (purple dot). Meanwhile, the value of RMSE are between 15-30 in Sumatera, Kalimantan, Java, Sulawesi and Papua (green dot). While, the value of RMSE are > 30 only in Cilacap and Sorong.

Previous studies about verification GSMAP MVK+ in Nepal for daily rainfall at a country level showed good result in capturing the spatial distribution of rainfall but underestimates with a correlation coefficient 0.79 and RMSE 4.8 (Shrestha et al, 2011). While in a basin of China (Poyang Lake Basin) showed GSMaP MVK+ generally underestimate precipitation amount, the correlation coefficient at daily scale is relatively low which less than 0.50 on average (Fu et al, 2011).

4. Conclusions
Generally, GSMaP_NRT is over-estimated from observation in Indonesia with the mean accuracy for daily rainfall estimation is 82.6%. The average of ME values in large islands such as Kalimantan, Papua & Mollucas are smaller than in small islands such as Nusa Tenggara. The value of daily MAE is near to zero, while monthly MAE value is higher. the GSMaP NRT estimation of rainfall is quite good in Indonesia.

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