

Bias correction of radar and satellite rainfall estimates and increasing its accuracy using modified merging

GIARNO*[#], MUHAMMAD PROMONO HADI*, SLAMET SUPRAYOGI* and SIGIT HERUMURTI*

*Departement of Geography Gadjah Mada University, Sleman, Indonesia

[#]Paotere Maritime Station Meteorology Climatology and Geophysical Agency, Makassar, Indonesia

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e mail : giarno@mail.ugm.ac.id

सार – मौसम रेडार में अभिनति सुधार और उष्णकटिबंधीय वर्षा मापन मिशन (TRMM) के वर्षा आकलन का उपयोग इसकी सटीकता में सुधार के लिए किया जाता है। यह सुधार आमतौर पर रेडार और उष्णकटिबंधीय वर्षा मापन मिशन दोनों के लिए अलग-अलग किया जाता है। भले ही सुधार अलग-अलग किए जाते हैं, लेकिन विलय के उपयोग से इन सुधारों के परिणामों में और सुधार किया जा सकता है। विलय के तरीकों में, संशोधित स्थानीय अभिनति, माध्य क्षेत्र अभिनति और प्रतिबंधीविलय, मकसार स्ट्रेट में आसपास के रिमोट सेंसिंग से अनुमानों को सही करने के लिए इस्तेमाल किए जाने वाले उपयुक्त तरीके हो सकते हैं। इस शोध का उद्देश्य रेडार और उष्णकटिबंधीय वर्षा मापन मिशन के वर्षा आकलनों को सही करना है और उनके संयोजन से अधिक सटीक वर्षा का आकलन करना है। सहसंबंध, वर्ग माध्य मूल त्रुटि (RMSE) और माध्य निरपेक्ष त्रुटि (MAE) का उपयोग करके प्रदर्शन कार्यनिष्पादन को मान्य किया जाएगा। प्राप्त परिणाम से पता चलता है कि संशोधित माध्य क्षेत्र अभिनति (Mod_MFB) और स्थानीय अभिनति (LB) मुख्यतः RMSE और MAE सटीकता बढ़ा सकते हैं, लेकिन सहसंबंध में नहीं। हालांकि, प्रतिबंधी विलय (CM) और संशोधित LB सहसंबंध को बढ़ाकर सटीकता में सुधार कर सकता है और RMSE और MAE में कमी कर सकता है। प्रतिबंधी विलय का संशोधन, स्थानीय अभिनति संशोधन और रिमोट सेंसिंग का मूल आकलन क्रमिक रूप से सर्वोत्तम तरीकों का क्रम है। इसके अलावा, तीनों डेटा प्रकारों को विलय करना दो प्रकार के डेटा को विलय करने से बेहतर नहीं है। हालांकि, 3 प्रकार के डेटा का संयोजन सटीकता को स्थिरता प्रदान करता है।

ABSTRACT. Bias correction in the weather radar and the tropical rainfall measuring mission (TRMM) rainfall estimates are used to improve its accuracy. This correction is usually done separately for both radar and TRMM. Even though the corrections are done separately, the results of these corrections can be further improved using the merging. Among the methods of merging, modified local bias, mean field bias and conditional merging may be suitable methods used to correct rainfall estimates from remote sensing surrounding in the Makassar Strait. The aim of this research corrects radar and TRMM rainfall estimates, then combining them to obtain more accurate rainfall estimates. The performance will be validated using correlation, root mean square error (RMSE) and mean absolute error (MAE). The result shows that modified mean field bias (Mod_MFB) and local bias (LB) can increase accuracy, mainly RMSE and MAE but not in correlation. However, conditional merging (CM) and modified LB can improve accuracy by increasing correlation and decrease RMSE and MAE. The modification of CM, LB modification and original estimation of remote sensing successively are the order of the best methods. Moreover, merging three data types is not automatically better than merging the two types of data. However, combination 3 types of data offer the stability of accuracy.

Key words – Bias correction, Radar, TRMM, Rainfall, Tropical maritime, Sulawesi.

1. Introduction

Accurate rainfall estimates are a crucial factor for many fields (Goovaerts, 2000; Jia *et al.*, 2011). Furthermore, this data is the main input of physical models to the forecast process of disaster-related events of both meteorological and hydrological fields for effective disaster management. At the present time, there are various sources of rainfall estimates available for public use, especially in developed countries, such as rainfall

observation at gauge stations or rainfall product estimation by satellite such as the tropical rainfall measuring mission (TRMM) and rainfall estimation derived from reflectivity of weather radar. Generally, it is accepted that rainfall observation at gauge stations is the best accuracy as the point observation provides a truth of ground rainfall, but the availability of rain gauge data is less available. Practically, spatial interpolation is one method to fill in un gauge locations (Keblouti *et al.*, 2012; Das *et al.*, 2017, Ly *et al.*, 2013). The other method applies rainfall estimates

from remote sensing both using radar or satellite to estimate rainfall distribution in a certain area (Stout *et al.*, 1968, Battan, 1973; Ramli and Tahir, 2011; Moreau *et al.*, 2009; Sebastianelli *et al.*, 2010; Li *et al.*, 2012; Xue *et al.*, 2013; Hu *et al.*, 2014; Matrosov *et al.*, 2014; Yeo *et al.*, 2015; Kirtsaeng and Chantraket, 2016; Montopoli *et al.*, 2017). However, the accuracy of remote sensing rainfall estimates is questioned and varies in each place (Praselia *et al.*, 2013; Giarno *et al.*, 2018a). In the monsoonal rainfall pattern, rainfall estimates of TRMM have better accuracy than local and equatorial rainfall patterns. Such as radars, which generally have good accuracy in the area around the placed radar, although topography distribution and rainfall persistence also influence accuracy (Giarno *et al.*, 2018c).

Weather radar or satellite measures indirect precipitation at a certain altitude, while a rain gauge is a direct measurement of rain quantity observed at a point near the ground surface. Thus, inequality of rain quantity always exists between the two data sets. There are attempts to utilize rain observed at gauge stations to adjust or correct rainfall estimates from radar and TRMM. There are many methods used in adjustment bias rainfall estimates. This ranges from simple to complicated processes. Michelson and Koistinen (2000) categorized the methods into two groups. The first group is to find a different ratio between gauge rainfall and radar rainfall estimates or mean field bias (MFB). Although MFB is the most efficient method to remove systematic biases, it does not account for a local variation of the bias that spatial interpolation techniques do (Fulton *et al.*, 1998; Tabary, 2007; Zhang *et al.*, 2014). The other way is to employ statistics and geostatistics methods to find a relation between the two sources such as spatial interpolation techniques (Chumchean, 2006).

In the tropics, the place where radar data are available means that there are two remote sensing rainfall estimates because TRMM data is also always available in the tropics. Maximizing these two data is by combining the estimated rainfall results from both radar and TRMM corrections. Combination or often called merging explores the strength and the weaknesses of each rainfall measurement (Goudenhoofdt and Delobbe, 2009). This idea is almost as same as combining predictions in Econometrics (Bates and Granger, 1969; Elliott and Timmermann, 2005; Giarno, 2014). The development of merging techniques on rainfall data was carried out since 1954 (McKee, 2015). Initially to combine rain gauge and radar data which later evolved to combine with satellite data. Broadly speaking, the merging radar method can be divided into two groups (Wang *et al.*, 2013), namely the bias reduction technique and the error minimization variance technique (McKee, 2015). The difference

between these two techniques is the emphasis on what is the reduction factor. The bias reduction technique focuses on the difference between rain sensing and rain gauge. While minimizing error variance focuses on reduction using the variance

Included in the class of reduction methods is the Mean Bias Correction or MFB (Hitschfeld and Bordan, 1954), Spatial Adjustment Brandes or BSA (Brandes, 1975), Local bias correction with ordinary kriging or LB (Babish, 2000) and Range dependent bias correction (Michelson and Koistinen, 2000). While the technique of minimizing error variance includes Bayesian data combinations, conditional merging, kriging external drift and objective analysis statistics. Among of merging methods, the local bias (LB) and mean field bias (MFB) are the fastest methods to use in merging techniques (Goudenhoofdt and Delobbe, 2009; McKee, 2015; Mahavik, 2017). Both of these techniques are fast because they only use the ratio of the comparison of estimated remote sensing and rainfall observed estimates.

Applying these techniques in the Indonesian maritime continent (IMC) are quite difficult to use, because rainfall events in this region are very random so that modified LB and MFB is required. The result showed that the performance of modified merging can increase accuracy. While modifying local bias (Mod_LB) is better than modifying the mean field bias (Mod_MFB). Among modified merging techniques, modified conditional merging is The best in rainfall merging in tropical maritime (Giarno *et al.*, 2018b). Use classification of the ratio can decrease root mean square error (RMSE) and mean absolute error (MAE), but Mod_LB is better in a reduction of RMSE and MAE than Mod_MFB. Comparing both of the methods in improvement of accuracy, they are still weaker than conditional merging (Mod_CM) (Sinclair and Pegram, 2005; Goudenhoofdt and Delobbe, 2009; Giarno *et al.*, 2018b). Moreover, the validation showed that CM could shrink value RMSE and MAE than original rainfall of remote sensing estimates, modified local bias and modified the mean field bias. Adding, CM also is the best in correlation evaluation than other merging methods.

The correction radar and TRMM rainfall estimates have been reduced bias its rainfall estimates. Then, if both of the result correction data available in an area, it is possible to combine them into new rainfall estimates that are expected to have better accuracy, beside maximize data availability. Filho (2004) performs this merging, but he used data that have the same temporal resolution. This scheme cannot be used in Indonesia since the limitation of the raw radar data. Rainfall observed data are generally in daily, but the radar reflectivity is in every 10 minutes.

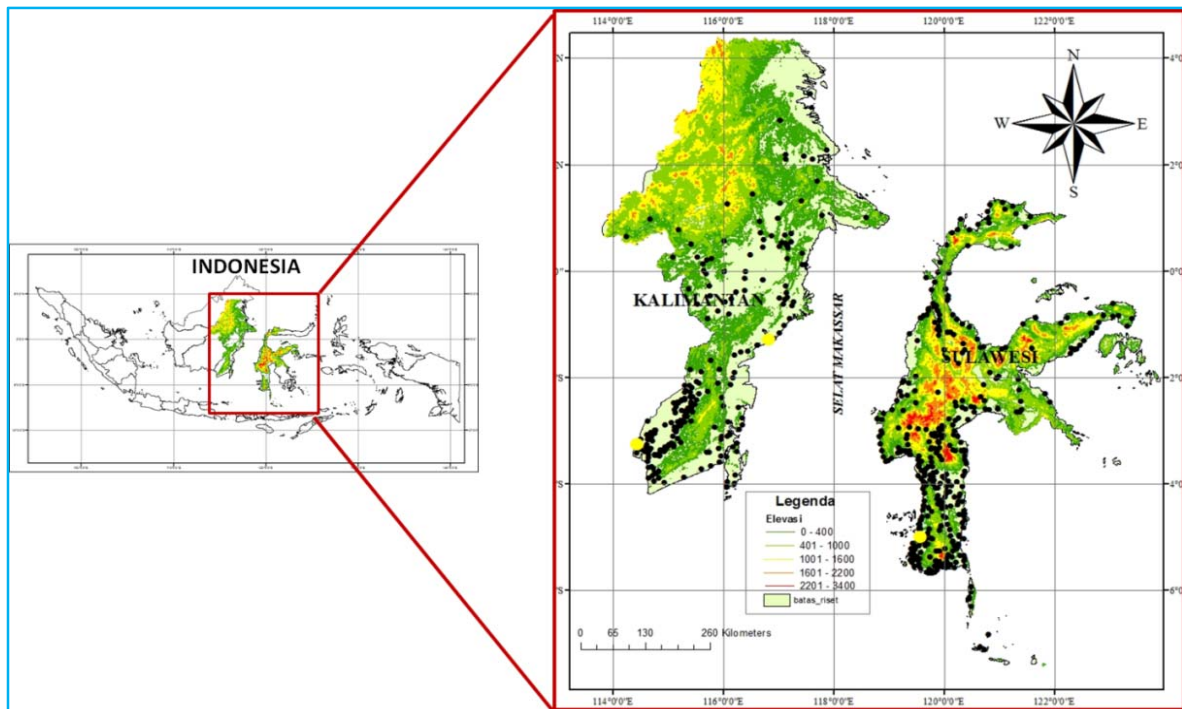


Fig. 1. Rain gauge locations (blue circles) and radar (big circles) in surrounding the Makassar Strait. Sulawesi has more mountains (red colour) than Kalimantan, while Kalimantan is dominated by terrain below 1000 meters (green colour)

While TRMM data are available every three hours and daily. This work starts with corrects rainfall estimates of radar and TRMM using rain gauge data, then merges them to obtain an improved rainfall prediction.

2. Data and methodology

2.1. Study area and data

This study locates in the surrounding of the Strait of Makassar, where all rain gauges and radars are located in Kalimantan Island and Sulawesi Island as Fig. 1. The Asian monsoon has an impact in increasing rainfall in this region, on the contrary, Australian monsoon less rain in this region. Moreover, rainfall is also influenced by water distribution. The Java Sea and Sulawesi Sea flank this region in the South and North. Also, elevation distribution in Kalimantan and Sulawesi is different. Where Sulawesi Island is a more complex elevation than Kalimantan that tends flatter. Besides monsoon, the other factors that can influence to a rainfall event in this region are local circulation (Hashiguchi *et al.*, 2013) and global phenomena such as Madden-Julian Oscillation (MJO, El Niño and the Southern Oscillation (ENSO), Indian Ocean Dipole (IOD) (D'Arrigo and Wilson, 2008; Hidayat and Kizu, 2010). Consequently results each location has an own rainfall pattern and makes the onset and withdrawal of rainfall dynamic (Giarno *et al.*, 2012).

In this work, we use 3 locations of radar that placed in Maros, Banjarmasin and Balikpapan. While rainfall observed is obtained by 631 rain gauge locations. Where 581 locations are used to merge model and 50 sites chosen for validating the correction. The existing of independent rain gauge is needed to evaluate the performance of the remote sensing rainfall estimate because basically predictions for estimating rainfall values in places where there is no rainfall measurement (Mitra *et al.*, 2013). Merging will be done daily and missing rainfall is neglected.

2.2. Methodology

The correction method for quantitative precipitation estimation (QPE) radar and satellite is basically almost the same as the merging method. The simplest and fastest these methods are used in this work, there is local bias (LB) and mean field bias (MFB) (Mc Kee, 2015). This method uses a ratio between rainfall from remote sensing and measured rainfall from the rain gauge. As a comparison, conditional merging (CM) and its modified is added. This method is often called the best method of merging (Goudenhoofd and Delobbe, 2009; Giarno *et al.*, 2018b).

The mean field bias (MFB) proposed for the correction of measurement remote sensing estimates

which was originally for radar (Hitschfeld and Bordan, 1954). This correction removes the bias in radar rainfall estimates from Z-R relationship (Borga *et al.*, 2002). Since rain gauges observed are assumed the true rainfall, then the mean of its accumulations is used to correct rainfall, remote sensing estimate by multiplying it by a ratio (C) obtained from the comparison of rainfall from remote sensing (R_i) and rain gauge (G_i) as Equation (1). The single ratio factor applied to the entire radar beam and initially, long-term bias correction recommended by Hitschfeld and Bordan (1954). However, a dynamic correction was adopted by Wilson (1979).

$$C = \frac{\sum_{i=1}^N R_i}{\sum_{i=1}^N G_i} \quad (1)$$

$$C_i = \frac{R_i}{G_i} \quad (2)$$

The local bias merging uses correction factors over the entire remote sensing domain which geostatistical interpolated such as ordinary kriging to distribute the correction factors over the remote sensing domain. Local correction (C_i) is obtained as in equation (2). While the distribution of correction, uses spatial interpolation and kriging is assumed as the most optimal interpolation technique (Babish, 2000). But, since the goodness interpolation method depends on time and place, in this work, it uses inverse distance weighting (IDW) to interpolate local correction.

This research implements a modification of LB and MFB to the correction of estimated daily rainfall. Ratios on MFB and LB are classified in 20 classes, which is the number of classes that can most improve accuracy (Giarno *et al.*, 2018b). This idea arises because the application of ratio weights on LB and MFB sometimes produces irrational weights. Random rainfall and many of them have zero value will be problematic if used as a divider. Therefore the weight classification is an alternative to correct TRMM estimation correction. In this study, this method will also be tested on radar rainfall estimates.

In the merging comparison, conditional merging (CM) is often considered the best method (Sik *et al.*, 2007; Goudenhoofd and Delobbe, 2009; Park *et al.*, 2017). This method was firstly proposed by Sinclair and Pegram (2005). The CM assumes that remote sensing rainfall estimates have a true field, but its value is unknown, while the rain gauges have an unknown field of

true values. Combines the strengths of each property as follows:

$$Z(s) = I_G(s) + \varepsilon_G(s) \quad (3)$$

$$R(s) = I_R(s) + \varepsilon_R(s) \quad (4)$$

$$M(s) = I_G(s) + \varepsilon_R(s) \quad (5)$$

where, $Z(s)$, $R(s)$, $M(s)$ respectively are rainfall from a rain gauge, remote sensing and CM result. While $I_G(s)$, $I_R(s)$ and $\varepsilon_G(s)$ are rain observed, remote sensing interpolation and error of rainfall of remote sensing interpolation respectively.

The original CM interpolate $I_G(s)$ and $I_R(s)$ in whole area using kriging technique, but in this work, we modified uses IDW interpolation. Moreover, not only in modifying CM, but also IDW as interpolation method that applied to all things that require interpolation as proposed Giarno *et al.* (2018b). Furthermore, the IDW interpolation can be used without worrying get the unsuitable variograms model since rain gauge scarcity and numerous locations have zero rainfall. As a resulted, this method can improve the accuracy in correction TRMM rainfall estimate separately. The radar also applied the procedure to correct radar rainfall estimation in 3 radar sites. Then, both resulted rainfall correction of 2 types remotes sensing rainfall estimates is corrected again or merged for new rainfall prediction.

Validation uses general statistical parameters of evaluating remote sensing rainfall estimates. The Pearson coefficient correlation (r) measures the strength and direction of rainfall estimates. While how large the deviation bias assessed by the root mean square error (RMSE) and mean absolute error (MAE). Moreover, the evaluation also considers rainfall intensity above moderate or more than 20 mm/day at the reference station. Since limited radar data, the evaluation matches radar data at all three locations and reference stations. If the reference stations have rainfall with more than 20 mm/day and exist data at least two radar locations. The results, evaluation only used 45 days.

3. Result

3.1. The process corrects and merges remote sensing rainfall estimates

First, the rainfall observed from rain gauge is used to correct remote sensing product both radar and TRMM rainfall estimates. The result of radar correction depends

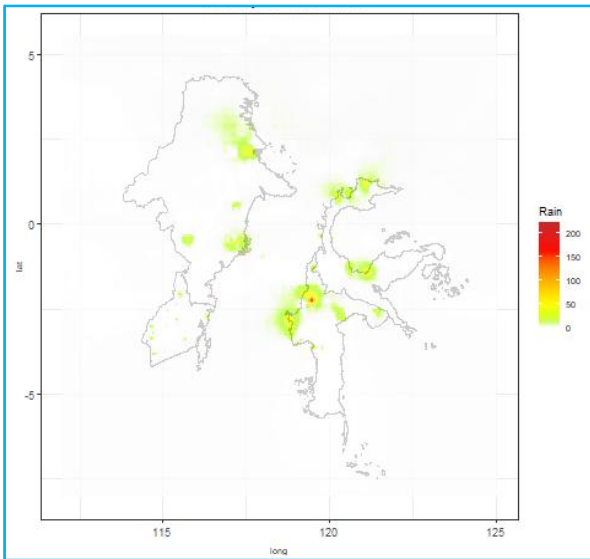


Fig. 2. Rainfall distribution resulted conditional merging Radar-Obs

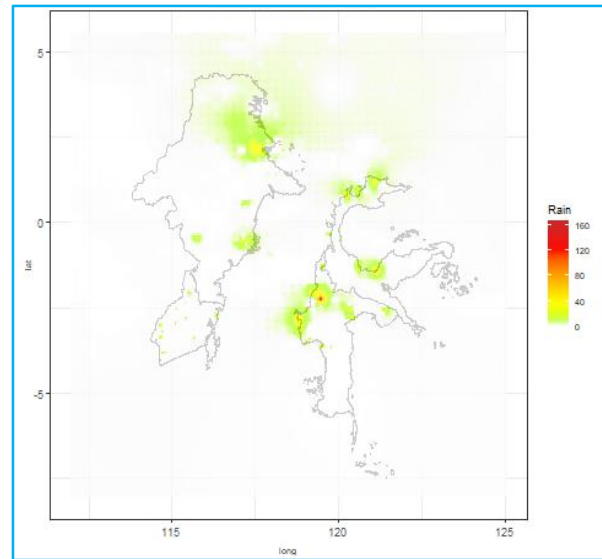


Fig. 4. Rainfall distribution resulted in conditional merging TRMM-Radar_Rain gauge

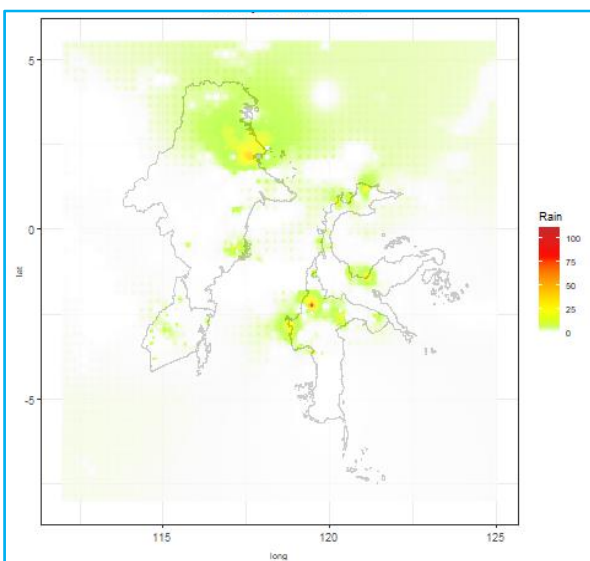


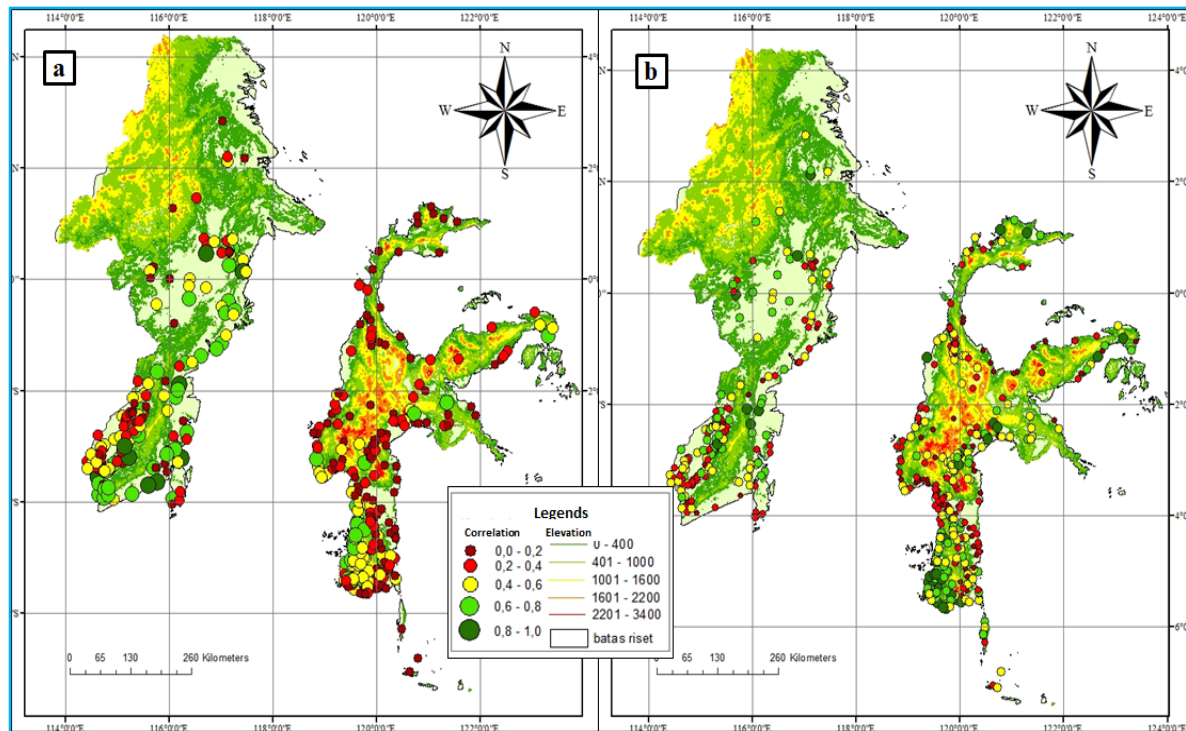
Fig. 3. Rainfall distribution resulted in conditional merging TRMM-Obs

on the radar beam and because there are 3 radars, the coverage increased to a wider area. However, in this study, the field of interest must be equal to Fig. 1, so the presence of rain gauge and radar data indeed influences the correction. The farther a location respect to radar and rain gauge, it makes the less precise. Therefore, this scheme almost corresponding to merging work, so then merging terms is often used to replace correction. Thus, it obtained new rainfall estimates, rain gauge-radar and rain gauge-TRMM. Combining rainfall between radar rainfall estimates and rain gauges observed will expand the

estimated range of the radar since correction associated with the presence of rain gauge and radar data. The radar coverage is limited, so the correction cannot be made if the distance is far apart from the radar. The merging will be strengthened with the existing rain gauge and radar data. If both of them measure high precipitation, then prediction also high. Conversely, if rainfall radar estimates obtain high prediction and rain observed small or no rain, merging will reduce estimate or not rain at all as depicted in Fig. 2.

On the other hand, the correction of TRMM only depends on the presence of rain gauge data. If there is no this equipment, the TRMM is relatively uncorrected. Moreover, the range of TRMM rainfall estimation has a wider than radar beam. Areas that are not covered by radar, it can still be attained by TRMM since its global observation. For example, in the northern and southern part of Kalimantan Island, where there are no rain gauge data and outside the radar range, but rainfall still detects using TRMM as depicted in Fig. 3. Moreover, TRMM merging has lower maximum values or underestimated than radar estimates. If in radar merging, the maximum rainfall is 200 mm, but on TRMM merging less than 100 mm. This means that the original value of the TRMM rainfall estimate is not as large as the original radar rainfall estimate. Rain gauge observed will correct the estimation of TRMM and radar.

Although rainfall observed has been used to correct TRMM rain, some places still have gaps. One's place may exceed far from a rain gauge, so it is difficult to correct because beyond the scope correction. As an example, in



Figs. 5(a&b). Distribution of correlation Mod_LB in (a) Radar - Obs and (b) TRMM - Obs

North Kalimantan, rainfall appeared in TRMM estimates, but using radar is not monitored at all. Interestingly, in the southern Kalimantan, the rain spots that only look a little on the radar merging, but it present to be stronger in the results of merging TRMM. Furthermore, in the central part of Sulawesi, there seems to be an increase in rainfall. The blending shows that in those places the rainfall was observed to be quite significant on TRMM but not on the radar. Since the radar range does not reach in Central Sulawesi, the possibility of additional rain comes from TRMM. In contrast to South Kalimantan, which is still tracked by radar, which means that estimates of low intensity rainfall are monitored by radar and TRMM.

Simultaneously merging of radar and TRMM can correct the lack of merging using only one type of data as shown in Fig. 4. The intensity of rainfall in the northern part of the Kalimantan Island, which is high on TRMM-Obs decreases if it is merged using Radar-Obs. In the southern part of Kalimantan rainfall is still seen in rainfall, which means that indeed there is rain in that place.

3.2. Validation

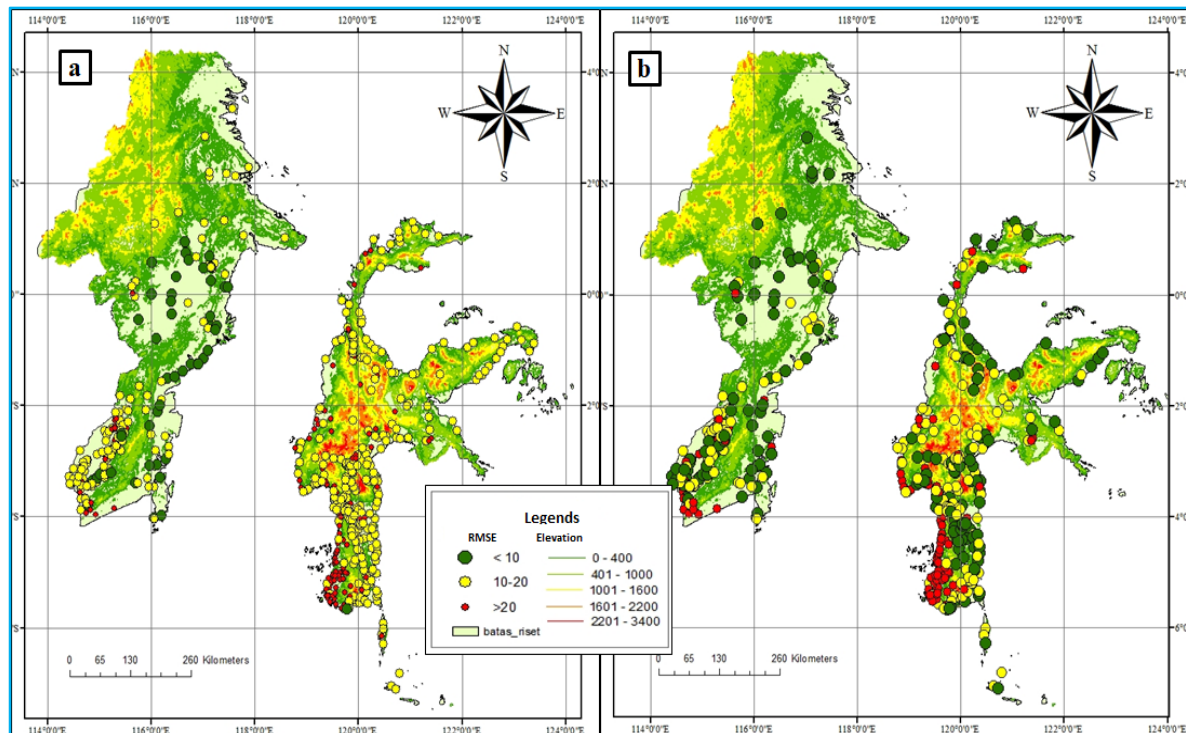
Evaluation is done by comparing the distribution of correlation, root mean square error (RMSE) and mean absolute error (MAE) for each method merging and types

of data. Finally, evaluation is served with all types of data and methods.

3.2.1. Modified local bias

Modification of local bias (Mod_LB) tested on combination Radar-Obs (rain gauge) and TRMM-Obs. There is a striking difference between the results of radar merging and TRMM merging as depicted in Fig. 5(a). Mod_LB on radar has the lowest correlation in plain areas that separate the Bawakaraeng Mountains and the Lompobatang Mountains, Sulawesi. There are many correlations below 0.4, even below 0.2 in this location. While other locations that have low correlation are on the eastern Sulawesi Island close to the Bone Gulf and also almost along the coast of Central Sulawesi which borders the Makassar Strait. The correlation above 0.6 is found on the north of the radar on the coast overlooking the Makassar Strait. Contrary with Sulawesi, the low correlation is found in the southern part of Kalimantan and in the north of the equator. In the south, a place that has a low correlation of less than 0.2 close to a place with a high correlation of more than 0.6.

The number low correlation on Mod_LB TRMM-Obs is less than Mod_LB Radar-Obs as depicted in Fig. 5(b). The low correlation located in the plain areas

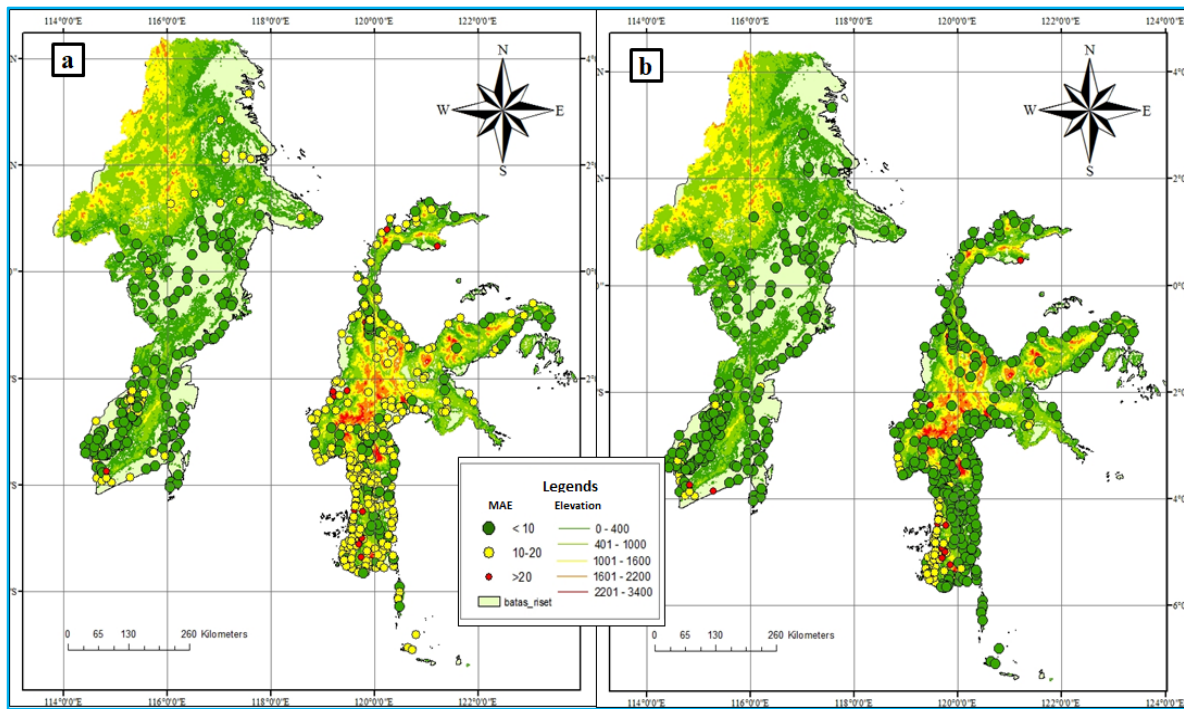


Figs. 6(a&b). Distribution of RMSE Mod_LB in (a) Radar - Obs and (b) TRMM - Obs

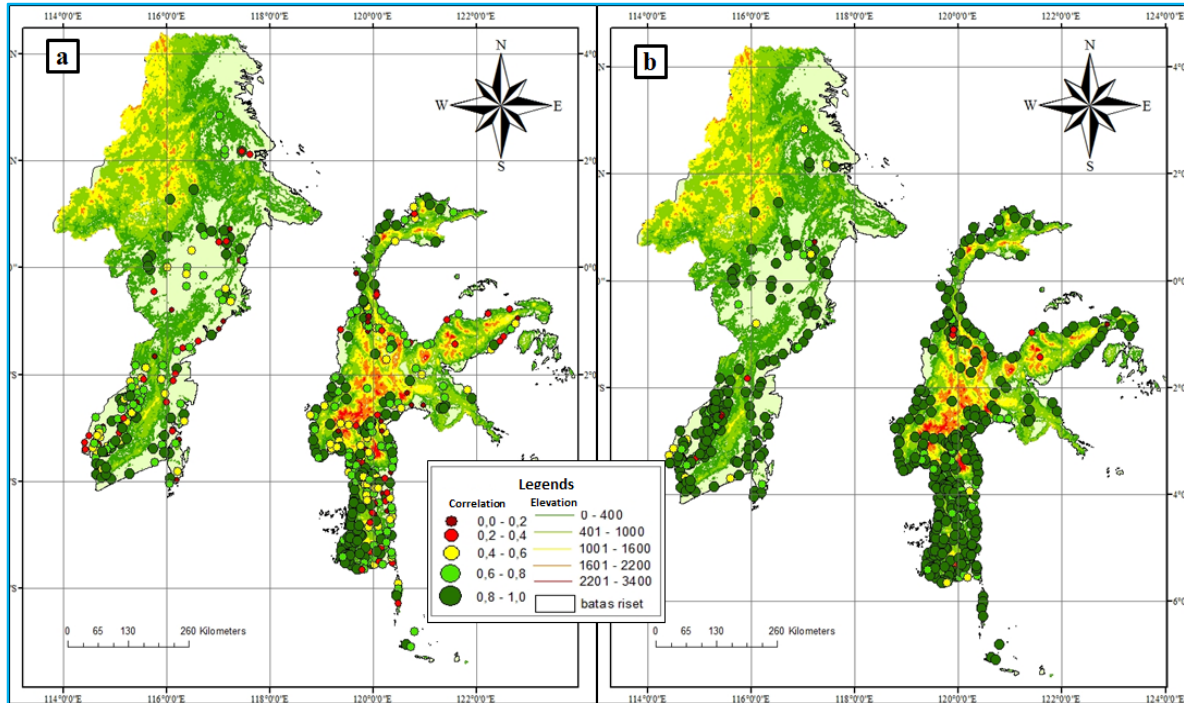
between the Bawakaraeng and the Lompobatang Mountains. Generally, its value below 0.2 and close to places of correlation 0.4 to 0.6. Locations that its correlations above 0.6 are found in the south of the Sulawesi Island and the northern Bone Gulf. However, in Kalimantan Island, the number of points that correlated more than 0.6 was little more than the merging radar. No locations that have a correlation higher than 0.8 in the results of Mod_LB Radar-Obs in Sulawesi. Conversely, in Kalimantan has found that a place with a correlation of more than 0.8. Some sites near the Banjarmasin radar have correlation of more than 0.8. Moreover, the evaluation of Mod_LB of TRMM-obs in Sulawesi depicted that these places have abundant places that have a correlation of more than 0.8, however striking ones are in Southern Sulawesi and the northern part of Bone Bay. While in Kalimantan, a high correlation is not as much as Mod_LB radar-obs and only found at several locations on the north central island and also at several points between Balikpapan and Banjarmasin. High correlation in Mod_LB radar-obs mostly located in the area adjacent to the radar. On the contrary, the Mod_TRMM-obs has a high correlation in a place that has a strong monsoonal and a local rainfall pattern in Sulawesi. Contrasting to Kalimantan Island, where the strong monsoonal rainfall patterns have a high correlation, but it is also found low correlation in adjacent the places.

The value of RMSE in Mod_LB Radar-Obs is the highest in the southern part of Sulawesi as depicted in Fig. 6(a). Moreover, this condition also found throughout the area adjacent to the Makassar Strait from the south to the middle of the island. Contrary to Kalimantan Island, there are only a few found such as close the Banjarmasin radar. While low RMSE values are found around the Kalimantan equator. Conversely, with Sulawesi that the majority of RMSE values range from 10-20 and are evenly distributed. While RMSE distribution in Mod_LB TRMM-Obs is better than Mod_LB Radar-Obs as shown in Fig. 6(b), where the number of points has a lower RMSE. The place with the highest RMSE is located on the southwest coast of Sulawesi, which is directly related to the Asian monsoon. It is found in low quantities of RMSE in Central Sulawesi, especially those adjacent to the Makassar Strait. Range RMSE between 0 to 10 is most commonly found in Kalimantan and intermittent with RMSE 10-20. While in Sulawesi, low RMSE is located in the lowlands separating the Lompobatang Mountains from the Bawakaraeng Mountains and in Central Sulawesi near the City of Palu.

Most places in Kalimantan have MAE less than 10 on Mod_LB radar-obs [Fig. 7(a)]. On the other hand, in Sulawesi, the MAE has generally been between 10 to 20. In this island, the class MAE spreads interspersed with



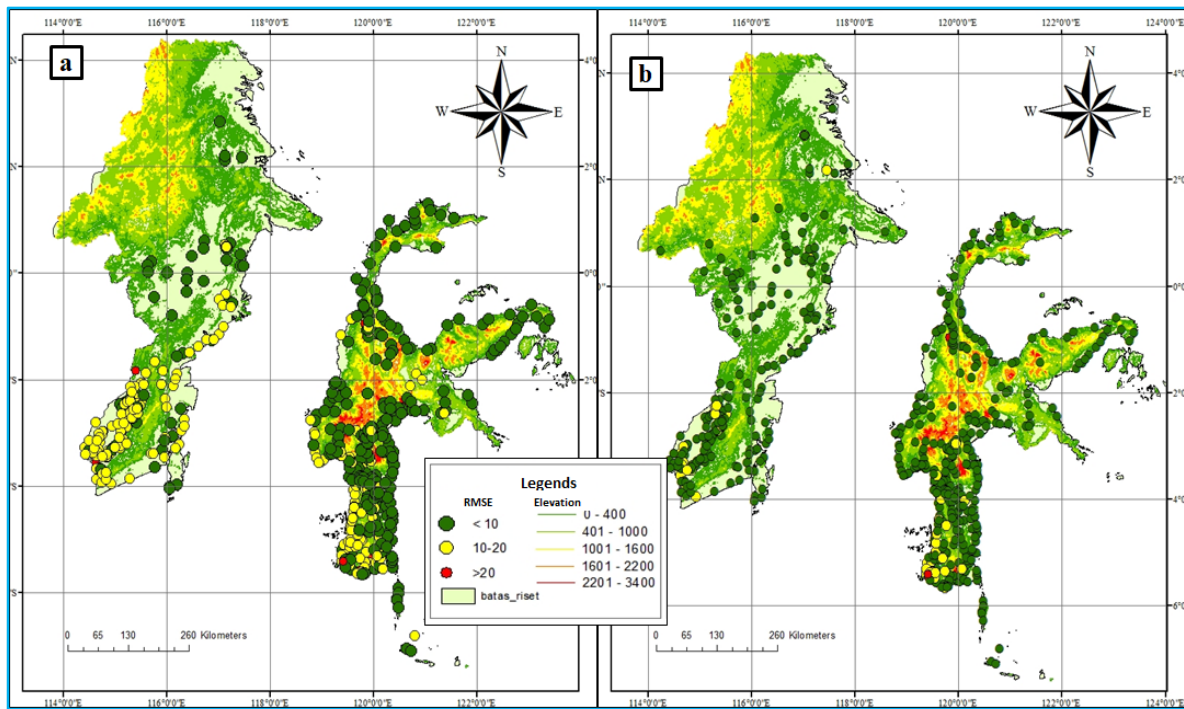
Figs. 7(a&b). Distribution of MAE Mod_LB in (a) Radar - Obs and (b) TRMM - Obs



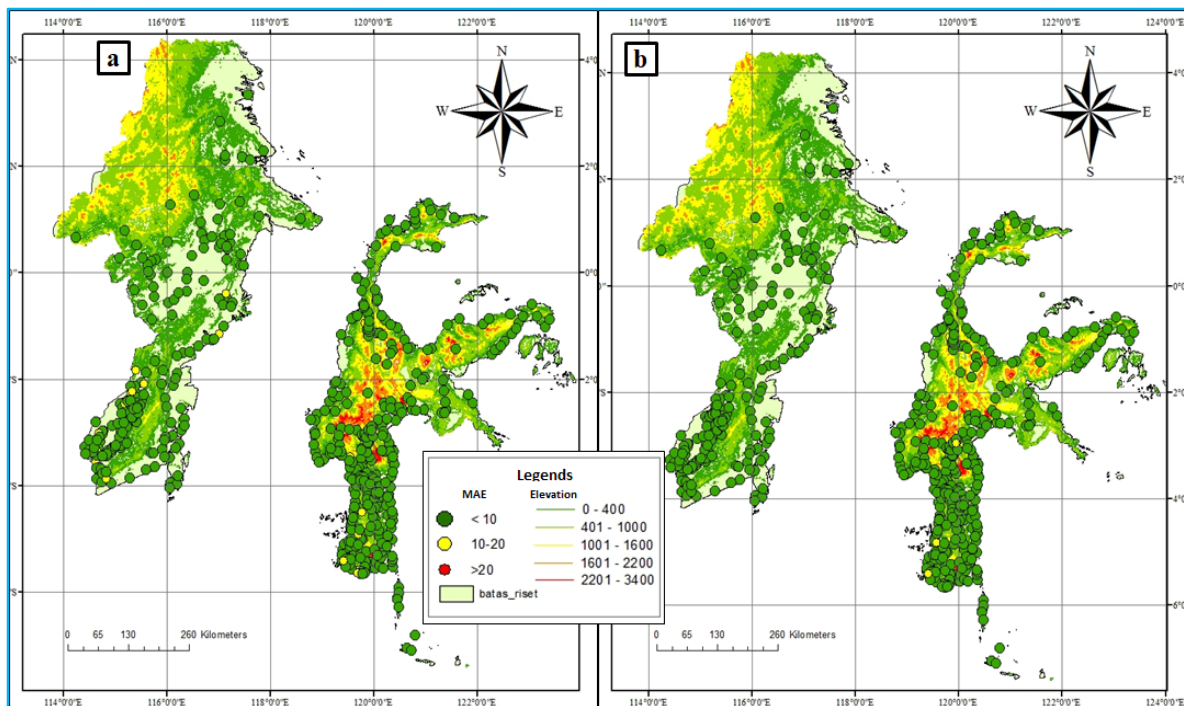
Figs. 8(a&b). Distribution of correlation Mod_CM in (a) Radar - Obs and (b) TRMM - Obs

MAE of less than 10 around the lowlands separating the Lompobatang and the Bawakaraeng Mountains and also

surrounding Palu City. Contrary with MAE on the radar, in Mod_LB TRMM-obs MAE values are almost all less



Figs. 9(a&b). Distribution of RMSE Mod_CM in (a) Radar - Obs and (b) TRMM - Obs



Figs. 10(a&b). Distribution of MAE Mod_CM in (a) Radar - Obs and (b) TRMM - Obs

than 10 in Kalimantan and Sulawesi as shown in Fig. 7(b). Only in the southwest, which is adjacent to southern

Sulawesi alone is the MAE value rather large, between 10 and 20.

TABLE 1

Comparison correlation, RMSE and MAE of merging result in the non independent locations

Methods	Correlation	RMSE	MAE
Radar	0.121	37.358	22.088
LB_Rad	0.230	17.529	10.771
CM_Rad	0.754	9.646	4.809
TRMM	0.126	20.596	11.009
LB_TRMM	0.349	15.151	6.148
CM_TRMM	0.909	6.123	2.810
LB3_simple	0.331	15.254	8.082
CM3_simple	0.855	6.926	3.481
LB3_Mod	0.316	16.385	9.032
CM3_Mod	0.806	8.244	4.132

TABLE 2

Comparison correlation, RMSE and MAE of merging result in the independent locations

Methods	Correlation	RMSE	MAE
Radar	0.123	34.448	19.956
LB_Rad	0.180	18.216	12.033
CM_Rad	0.272	15.502	7.871
TRMM	0.129	18.622	9.387
LB_TRMM	0.288	15.516	6.814
CM_TRMM	0.400	13.819	7.042
LB3_simple	0.274	15.758	8.909
CM3_simple	0.360	14.167	7.273
LB3_Mod	0.252	17.165	10.162
CM3_Mod	0.343	14.515	7.478

3.2.2. Modified conditional merging

The comparison between modified LB (Mod_LB) and modified conditional merging (Mod_CM) show that Mod_CM improved in correlation, RMSE and MAE comparing Mod_LB as depicted in Figs. 5-7 and Figs. 8-10. The value of correlation in Mod_CM lies between strong and very strong or 0.6-1.0 in the almost entire research area. Meanwhile correlation of Mod_LB varies from low to very strong as shown in Fig. 8(a). Evaluation Mod_CM of TRMM showed almost all places have correlation above 0.6, except in some places in the Central Sulawesi and only one place in Kalimantan as shown in Fig. 8(b). However, in the radar merging, the value of the correlation is more variable than merging TRMM. The excessive far locations from the radar radome and blocked by mountains appear to be a very low correlation in Sulawesi. However, mountain effect in Kalimantan is less visible since the place is indeed relatively plain and not as complex as Sulawesi topography. While using Mod_CM Radar-Obs found in several places close to the radar turned out to have a low correlation.

Application Mod_CM [Fig. 8(a)] produces a significant reduction of RMSE when comparing to Mod_LB [Fig. 9(a)]. Evaluation showed the distribution of RMSE shows that almost areas have RMSE > 20 in Mod_LB that decreases when compared to Mod_CM. While, in the southern part of Sulawesi Island, which is almost region has RMSE > 15 in Mod_LB but decreased to 0-10 using Mod_CM. Likewise, variations of RMSE that are occasionally large and drastically reduced both in Kalimantan and Sulawesi. Based on the value of RMSE, Mod_CM TRMM-Obs is more reliable than radar-obs.

Many places in Kalimantan have 10-20 in RMSE when using Radar-Obs compared to TRMM-Obs that has RMSE 0-10. Both Mod_CM on merging radar and TRMM produce MAE all below 10 as depicted in Figs. 10(a&b). Only in a few points are in the southwest of Eastern Sulawesi and the Southern Kalimantan, the MAE value has still worth 15. Based on the above explanation, Mod_CM is the most reliable for combining estimated remote sensing rainfall and rainfall observed.

3.2.3. Merging three types of rainfall data

Merging that uses 3 types of data while showing the best CM accuracy. Validation uses statistical indicators such as root mean square error (RMSE), mean absolute error (MAE) and correlation to assess the difference in accuracy between merging TRMM-Obs, Radar-Obs and Radar-TRMM-Obs which results are tabulated in Tables (1&2). It contains the performance of dependent locations in the estimation of radar (radar) rainfall and merging, using a modification of local bias (LB_Rad) and conditional merging (CM_Rad). TRMM rainfall estimation and modification are locally biased (LB_TRMM) and conditional merging (CM_TRMM). Finally merging the radar and TRMM uses a simple method or gives 0.5 weights to each rain estimate, namely LB3_simple and CM3_simple and uses variance for LB3_Mod and CM3_Mod.

Based on the value of RMSE, MAE and its correlation, generally the results of merging are better than just using estimates of rainfall remote sensing for both radar and TRMM only. Compared to local modifications to bias or Mod_LB, modification of conditional merging or Mod_CM is better in the locations that are not

independent. Parameter values are almost doubled in comparison, both RMSE, MAE and correlation compared to Mod_LB. But this Mod_LB is still better than the original estimation of radar and TRMM satellite.

Performance rainfall estimation in independent location shows that Mod_CM on TRMM is more effectively than other merging technique, original remote sensing rainfall estimates as shown in Table 2. The average correlation of Mod_CM on TRMM close to 1, which is 0.909. Furthermore, evaluation also obtained RMSE below 10 and MAE is less than 5. Moreover, the next best merging is CM uses all three types of data, both simple (CM3_simple) and using the variance (CM3_Mod) with a correlation of 0.855 and 0.806. Comparison these two techniques showed that complex methods wasn't always better than simple ones. The simple method (CM3_simple) that only uses the same weight for each variable has a better correlation, RMSE and MAE than complicated such as CM3_Mod. The validation using independent locations shows that the value of the correlation below 0.5, while most RMSE above 10. No location has MAE below 5. Based on the correlation value, CM modified RMSE and MAE are still the best compared to using the original or biased local estimates. However, modified local bias is still better than using the original estimation of remote sensing.

4. Discussion

Merging is essentially a correction of remote sensing rainfall estimates such as radar and satellites using the results of rain gauge observed (McKee, 2015). Of course, the results of this correction should be more accurate than rainfall estimates from radar or satellites. Normally, rainfall from rain gauge is considered the most accurate and must be represented rainfall on the surface. The rain gauge data are point data, different from remote sensing radar and satellite data that describe spatial rain. The merging takes advantage of the advantages and disadvantages of remote sensing and rain gauge so that better results are obtained when compared to using only one (Wilson, 1979; Erdin, 2009). The result shows that the merging technique has been shown to increase the correlation value and reduce RMSE compared to the estimation of remote sensing without merging. This has led to widespread merging as in India (Mitra *et al.*, 2009), South Korea (Sik *et al.*, 2007); China (Xie and Xiong, 2011); America (Ciach *et al.*, 2007) and Europe (Schiemann *et al.*, 2011; Pulkkinen *et al.*, 2014). The use of weights in the bias mean field or MFB uses a comparison of the amount of rainfall estimated from remote sensing compared to the amount of rain gauge rainfall. Although this method can improve the accuracy of rain remote sensing estimates (Sik *et al.*, 2007; Delobbe

et al., 2008; McKee, 2015), the decline is globally on average, not spatially described. Local merging can correct this deficiency by calculating the weights in each location. The use of weights in each location to merge daily rainfall, especially in the maritime continent, such as in the Makassar Strait, produces a disproportionate weight. For this reason, modification is needed to make the weight more proportional by making a grouping of weights. The evaluation results show that this method can increase the correlation value and reduce the root mean square error (RMSE) and mean absolute error (MAE).

Using CM in many researches preferable than LB and MFB, although all could improve accuracy rainfall estimation of remote sensing estimates (Sik *et al.*, 2007; Goudenhoofdt and Delobbe, 2009; Park *et al.*, 2017). This technique can also call kriging with radar-based error correction (KRE) that proposed remote sensing rainfall estimates such as radar or TRMM have an estimate unknown a true or true field. Instead, rain gauge produces unknown fields of the correct value. Fundamentally, CM combines both corrections so that the correction of the rain gauge is included in the estimated remote sensing calculation. However, the problem in CM in this research area is the interpolation used. Although the standard on CM uses kriging interpolation, but modelling variogram has a big difficulty in the rain event which has a lot of 0 rainfall accumulation. Interpolation estimates using values around a point with a certain weight so that the result of 0 in rainfall interpolations makes no rainfall. Therefore, the interpolation will be good if at each point have a value above 0, such as monthly or annual rainfall. However, in the daily rain event since random, especially in this study area there are many whose values are 0 even though the place is close and in the rainy season. Therefore in this work, the merging results were changed to a certain extent according to the percentage of daily rain in the region. The evaluation showed that modified CM the valuable merging, which can most increasing in correlation and decrease MAE and RMSE. The order of the best models in this work is the modification of CM, LB modification and original rainfall estimation of remote sensing.

Merging which combines three different types of data is still very rare. Different from Filho (2004) that merged by combining the rain gauge first and then the merging results were reset with estimates of satellite rain. This research proposed an alternative to merging three types of data by simultaneously merging rain gauges and radar (TRMM) - Radar. Moreover, the second result of merging is turned back into one new rainfall estimate. The evaluation shows that merging these three data types is not automatically better than merging the two types of data. Even though merging these three data types is not always better than merging TRMM-Obs, but this merging offers

stability. Merging is the same as the combination of time series forecasting. The ups and downs of the two models when combined should always be around the predicted variables, so the merging of the 2 models does offer improvements in accuracy and predictive stability (Giarno, 2014).

5. Conclusions

Modified mean field bias (Mod_MFB) and local bias (LB) are proven to increase accuracy, mainly in reducing root mean square error (RMSE) and mean absolute error (MAE). But, increasing correlation is rather difficult using both methods. However, conditional merging (CM) and modified LB with 20 classes besides can increase the value of the correlation, also can decrease RMSE and MAE. The modified LB can be considered as the best method for stabilization of MAE, while CM is the best method to decrease RMSE and MAE. The order of the best merging among methods in this study is the modification of CM, LB modification and original estimation of remote sensing. Moreover, merging three data types is not automatically better than merging the two types of data. However, merging offers the stability of accuracy.

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