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Evaluation of multiple gridded precipitation datasets using gauge observations over Indonesia during the Asian-Australian monsoon period

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सार – ग्रिडेड वर्षण डेटासेट उपग्रह प्रेक्षणों और पुनर्विश्लेषण मॉडल आउटपुट से व्यापक रूप से उपलब्ध हैं। हालाँकि, दुनिया के विशिष्ट क्षेत्रों में इसका प्रदर्शन भिन्न-भिन्न हो सकता है और यह कई कारकों, जैसे कि ग्रिड डेटा स्थानिक विभेदन, वर्षा अनुमान एल्गोरिदम, भौगोलिक स्थिति, ऊंचाई और क्षेत्रीय जलवायु स्थितियोंपर निर्भर करता है। इस अध्ययन का उद्देश्य 12 साल की अवधि (2001-2012) में विभिन्न समय के पैमाने पर वर्षामापन के साथ प्रत्यक्ष तुलना के माध्यम से इंडोनेशिया के 13 ग्रिडेड वर्षा डेटासेट के निष्पादन को रिपोर्ट करना है। परिणाम बताते हैं कि , दैनिक समय के पैमाने पर , MERRA2 और CPC ने अन्य डेटासेट से बेहतर प्रदर्शन किया , लेकिन इंडोनेशिया में वर्षामापी डेटा को कम करके आंका गया , इसके बाद GPCC का स्थान रहा। हालाँकि, MERRA2 में CPC की तुलना में छोटे बदलाव और पूर्वाग्रह हैं। मासिक और वार्षिक समय -सीमा पर, CPC को सबसे अच्छा प्रदर्शन करने वाला डेटासेट पाया गया, इसके बाद MERRA2, GPM-IMERG, GPCC और TRMM (TMPA) का स्थान रहा, जबकि JRA55 ने सभी समय-मानों पर सबसे खराब प्रदर्शन दर्ज किया, इसके बाद ERA-अंतरिम का स्थान रहा। DJF और MAM की तुलना में JJA और SON के दौरान सभी डेटासेट का प्रदर्शन बेहतर था। सबसे अच्छा प्रदर्शन इंडोनेशिया के दक्षिणी (S) क्षेत्र में पाया गया, जबकि सभी महीनों और डेटासेट के लिए सबसे खराब प्रदर्शन पूर्वोत्तर (NE) क्षेत्र में था। DJF (एशियाई शीतकालीन मॉनसून) और JJA/SON (ऑस्ट्रेलियाई शीतकालीन मॉनसून) के दौरान सर्वश्रेष्ठ प्रदर्शन क्रमशः उत्तर पश्चिम (NW) और दक्षिणी (S) क्षेत्रों में पाए गए। GSMaP, MERRA2, CPC और CMORPH को छोड़कर, अधिकांश डेटासेट इंडोनेशिया में वर्षामापी डेटा का अनुमान लगाते हैं।

ABSTRACT. Gridded precipitation datasets are widely available from satellite observations and reanalysis model outputs. However, its performance in specific regions in the world may vary and depends on several factors, such as grid data spatial resolution, rainfall estimation algorithms, geographical location, elevation and regional climate conditions. This study aims to report on 13 gridded precipitation datasets' performance over Indonesia through direct comparisons with rain gauge measurements at various time scales over a 12-year period (2001-2012). The results show that, at daily timescales, the MERRA2 and CPC outperformed other datasets but tended to underestimate the rain gauge data in Indonesia, followed by GPCC. However, MERRA2 has smaller variation and bias than CPC. On monthly and annually timescales, CPC was found to be the best-performing dataset, followed by MERRA2, GPM-IMERG, GPCC and TRMM (TMPA), while JRA55 registered the worst performance at all timescales, followed by ERA-Interim. The performance of all datasets was better during JJA and SON than during DJF and MAM. The best performances were found in the southern (S) region of Indonesia, while the worst were in the northeast (NE) region for all months and datasets. The best performances during DJF (Asian Winter Monsoon) and JJA/SON (Australian Winter Monsoon) were found in the northwest (NW) and southern (S) regions, respectively. Most datasets overestimate the rain gauge data over Indonesia, except for GSMaP, MERRA2, CPC and CMORPH.

Key words – Precipitation datasets, Asian-Australian monsoons, Surface observations, Satellite observations, Indonesia.

1. Introduction

Rain gauge observations are usually used for manual measurement of precipitation directly on the surface at a point scale. In Indonesia, the number of meteorological stations is still limited and sparsely distributed, especially in mountainous and inaccessible or remote areas that are likely not available. Measurement of rainfall is very important because the onset and peak of the wet and dry seasons in Indonesia are determined based on rainfall (Wati *et al*., 2019). The variability of rainfall in Indonesia is strongly influenced by the activity of the Asian-Australian Monsoon. The Asian monsoon affects the variability of rainfall during the rainy season and the Australian monsoon affects the variability of rainfall during the dry season (Robertson *et al*., 2011). The utilization of existing gridded precipitation datasets can cope with the lack of rain gauge observations and the daily missing-values problems in the observation time series.

There are several categories of gridded precipitation datasets, including rain gauge-based, satellite-based, mixed gauge-satellite-based and reanalysis model datasets (Higgins *et al*., 1996; Xie and Arkin, 1997; Jones and Moberg, 2003; Schneider *et al*., 2011; Arakawa and Kitoh, 2011). There are several rain gauge-based gridded datasets available. Their quality depends on the station density, interpolation methods, spatial resolution, altitude gradient and climate (Merino *et al*., 2021). Satellites measure rainfall by estimating the amount of electromagnetic radiation (or energy) emitted or reflected from the tops of clouds or raindrops themselves. The satellite generates data in the form of a grid, the size of which varies. The lower the grid resolution, the better the data describes the variation in rainfall between regions. Meanwhile, reanalysis datasets involve a variety of observational data synthesis (radiosondes, satellites, buoys, planes and ships) that use the assimilation scheme with climate models.

Previous studies have evaluated the performance of several gridded precipitation datasets in Indonesia, but the number of gridded datasets used was limited (less than 10) and focused more on rain-gauge and satellite-based datasets, excluding reanalysis datasets (Wati *et al*., 2021, 2022). These studies found that MSWEPv2, SA-OBS, TMPA 3B42V7 and GPM-IMERG are the best datasets that generally outperformed other datasets in Indonesia. This study aims to evaluate the statistical performance of 13 gridded precipitation products, including reanalysis datasets, over Indonesia through direct comparisons with rain gauge datasets at various time scales during the period of 2001-2012 (12 years), particularly during the Asian-Australian Monsoon period.

2. Data and methodology

2.1. *Gridded precipitation datasets*

The summary of thirteen precipitation datasets used in this study is presented in Table 1. It consists of nine rain gauge and satellite-based datasets which have a daily temporal resolution and four reanalysis datasets with an hourly (ERA5 and MERRA2), a 3-hourly (JRA55) and a 12-hourly (ERA-Interim) temporal resolutions. For analysis purposes, reanalysis datasets are then converted to daily resolution. It should be noted that the spatial resolutions of datasets are 0.1° for GPM-IMERG and GSMaP; 0.25° for CHIRPS, CMORPH, PERSIANN, TRMM and ERA5; 0.5° for CPC; 0.562° for JRA55; 0.5° × 0.67° for MERRA2; 0.75° for ERA-Interim; and 1° for GPCC and GPCP.

2.2. *Observation datasets*

For observation datasets, rain gauge data from 82 BMKG stations in Indonesia from 2001-2012 (12 years) has been used as the reference dataset (Fig. 1). These times span the years between observations and all precipitation datasets being compared. The rainfall data is the same observed daily precipitation dataset that was used in Supari *et al*. (2017). For regional analysis, Indonesia is simply divided into three regional clusters based on the typical annual rainfall pattern (Aldrian and Susanto, 2003), as follows (Fig. 1):

(*i*) Northwest (NW) region containing 24 stations, which typically has two peaks of rainy season in a year

(*ii*) Northeast (NE) region containing 12 stations, which typically has one peak of rainy season during JJA and one peak of dry season during DJF.

(*iii*) South (S) region containing 45 stations, which typically has one peak of rainy season during DJF and one peak of dry season during JJA.

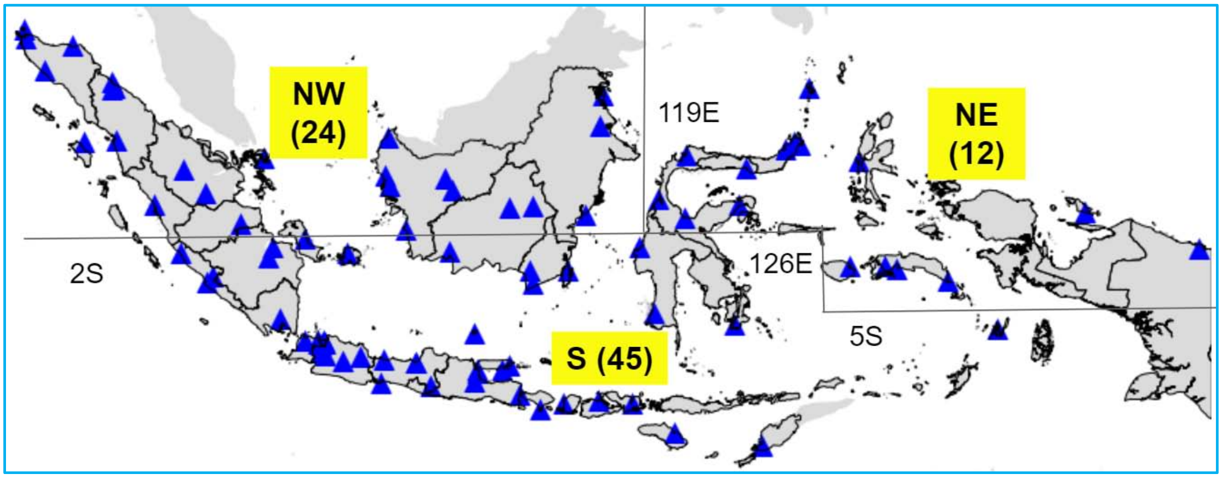

Fig. 1. Spatial distribution of rain gauge stations and simple clusters based on a typical rainfall regions

TABLE 1

Summary of Gridded Precipitation Datasets used in this study

S. No.	Dataset type	Dataset product	Resolution		Period	References
			Spatial	Temporal		
1.	Gauge-based	CPC-Unified	0.5°	daily	1979-present	Chen *et al*. (2008)
2.	Gauge-based	GPCC V2018	1.0°	daily	1982-2016	Schamm *et al*. (2014)
3.	Gauge and satellite-based	GPCP V1.2	1.0°	daily	1997-2015	Huffman *et al*. (2001)
4.	Satellite-based	CHIRPS v2.0	0.25°	daily	1981-present	Funk *et al*. (2015)
5.	Satellite-based	CMORPH_V1.0_ADJ Bias-corrected	0.25°	daily	1998-present	Joyce *et al*. (2004)
6.	Satellite-based	PERSIANN-CDRv01r01	0.25°	daily	1983-present	Ashouri *et al*. (2015)
7.	Satellite-based	TRMM (TMPA) 3B42V7	0.25°	daily	1998-2019	Huffman *et al*. (2007; 2010)
8.	Satellite-based	GPM-IMERG V06 Gauge-calibrated Final product	0.1°	daily	2000-present	Huffman *et al*. (2015; 2020)
9.	Satellite-based	GSMaP Gauge-calibrated	0.1°	daily	2000-present	Kubota *et al*. (2007; 2020)
10.	Reanalysis	ERA-5	0.25°	hourly	1950-present	Hersbach *et al*. (2020)
11.	Reanalysis	ERA-Interim	0.75°	12-hourly	1979-2019	Dee *et al*. (2011)
12.	Reanalysis	JRA55	0.562°	3-hourly	1958-present	Kobayashi *et al*. (2015)
13.	Reanalysis	MERRA2	0.5° × 0.67°	hourly	1980-present	Gelaro *et al*. (2017)

2.3. *Statistical metrics*

This study implemented the point to grid comparison approach using the nearest neighbor method (the dataset grid location is the same as the point of the observation station site). Furthermore, the comparison is conducted by calculating simple statistical metrics of time sequence, including Pearson Coefficient Correlation (*r*; Eqn. 1), Root Mean Squared Error (RMSE; Eqn. 2) and Bias / Error (Eqn. 3). *r* is used to measure the degree of relationships between observed and grid datasets. RMSE is used to describe the level of accuracy between

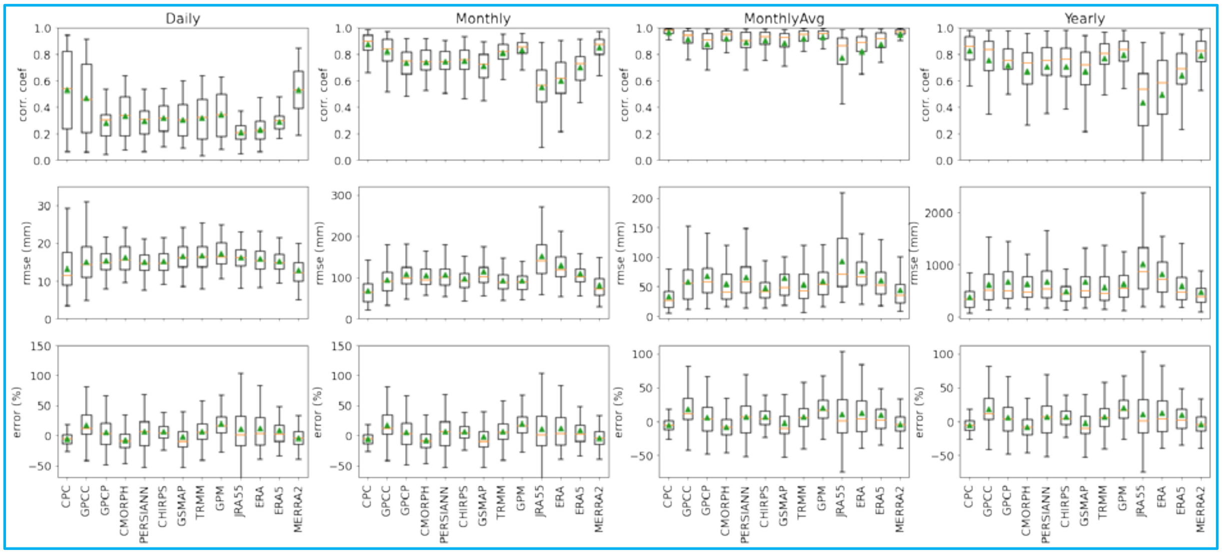

Fig. 2. Box plot of coefficient correlation, RMSE and bias (error) from all observation stations for all months at daily, monthly, monthly-average and annually timescales. Green triangles represent the mean values

TABLE 2

The mean values of statistical measures for all months. The best values are bold

Dataset type	Dataset	Daily		Monthly		Annually		Bias (%)
		r	RMSE (mm/day)	*r*	RMSE (mm/month)	*r*	RMSE (mm/year)	
Rain gauge-based	CPC	**0.53**	13.27	**0.88**	**69.48**	**0.83**	**382.61**	-4.87
	GPCC	0.47	15.06	0.82	94.04	0.76	618.78	18.28
	GPCP	0.28	15.44	0.74	108.74	0.72	665.82	5.37
Satellite-based	CMORPH	0.34	16.27	0.74	105.95	0.67	627.77	-7.67
	PERSIANN	0.30	15.12	0.75	107.35	0.71	666.51	7.08
	CHIRPS	0.32	15.27	0.75	97.16	0.71	490.16	7.17
	GSMAP	0.31	16.71	0.71	115.77	0.67	677.27	**-1.56**
	TRMM	0.32	16.80	0.81	92.44	0.77	564.20	6.70
	GPM	0.35	17.27	0.83	93.63	0.80	634.04	20.50
Reanalysis	JRA55	0.21	16.35	0.55	151.80	0.44	1021.17	11.17
	ERA	0.23	15.97	0.60	130.49	0.50	822.12	12.37
	ERA5	0.29	15.23	0.70	109.97	0.64	594.02	9.66
	MERRA2	**0.53**	**12.96**	0.85	81.57	0.79	480.86	-4.20

observation data and grid data. Bias / Error is used to determine rainfall estimation results from grid data that is overestimated (Bias > 0) or underestimated (Bias < 0).

$$r = \frac{\sum\left(G_i - \overline{G}_i\right)\left(S_i - \overline{S}_i\right)}{\sqrt{\sum\left(G_i - \overline{G}_i\right)^2}\sqrt{\sum\left(S_i - \overline{S}_i\right)^2}} \quad (1)$$

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum\left(S_i - G_i\right)^2} \quad (2)$$

$$\text{BIAS/Error} = \left(\frac{\sum S_i}{\sum G_i} - 1\right) \times 100 \quad (3)$$

Fig. 3. The seasonal mean values of coefficient correlation, RMSE and bias (error) from all observation stations at daily and monthly timescales

TABLE 3

The seasonal values of statistical measures
(The best values are bold)

Dataset Type			Rain gauge-based			Satellite-based						Reanalysis			
Data/Season/Metrics			CPC	GPCC	GPCP	CMORPH	PERSIANN	CHIRPS	GSMAP	TRMM	GPM	JRA55	ERA	ERA5	MERRA2
Daily	DJF	r	**0.51**	0.45	0.23	0.31	0.25	0.29	0.30	0.30	0.33	0.16	0.17	0.25	**0.51**
		RMSE	15.81	17.96	18.45	19.40	17.94	17.83	19.53	19.87	20.28	19.47	19.17	18.09	**15.47**
	MAM	r	**0.50**	0.44	0.24	0.29	0.25	0.27	0.25	0.29	0.30	0.16	0.18	0.23	0.49
		RMSE	13.47	15.70	16.01	16.91	15.60	15.74	17.34	17.41	18.09	16.89	16.26	15.64	**13.41**
	JJA	r	**0.52**	0.48	0.28	0.32	0.28	0.29	0.28	0.32	0.36	0.22	0.24	0.28	**0.52**
		RMSE	9.78	10.73	11.35	12.07	11.39	11.83	12.51	12.37	12.62	11.95	11.55	11.30	**9.53**
	SON	r	**0.51**	0.46	0.27	0.31	0.27	0.30	0.28	0.30	0.32	0.21	0.22	0.28	**0.51**
		RMSE	12.24	13.99	14.15	14.72	13.87	14.06	15.59	15.66	16.15	15.10	14.90	14.00	**11.81**
Monthly	DJF	r	**0.82**	0.74	0.60	0.62	0.62	0.60	0.57	0.73	0.77	0.32	0.37	0.52	0.78
		RMSE	**82.74**	109.00	127.42	126.35	128.90	116.15	132.91	107.55	107.47	179.62	155.88	132.17	98.49
	MAM	r	**0.81**	0.72	0.59	0.59	0.60	0.60	0.53	0.72	0.74	0.38	0.40	0.53	0.75
		RMSE	**67.19**	96.83	108.16	104.76	106.57	95.39	112.39	90.44	92.77	148.55	124.10	106.58	80.15
	JJA	r	**0.86**	0.83	0.72	0.67	0.71	0.71	0.65	0.78	0.81	0.57	0.60	0.67	0.83
		RMSE	**48.80**	64.25	74.38	77.39	74.34	69.37	87.73	64.88	66.03	105.40	91.26	77.57	55.78
	SON	r	**0.86**	0.82	0.72	0.71	0.73	0.73	0.70	0.79	0.82	0.55	0.58	0.70	0.84
		RMSE	**61.53**	86.76	103.13	95.79	98.37	88.89	107.77	87.26	89.91	139.17	127.02	101.49	72.30
	DJF	Bias (%)	-5.82	13.91	**-1.21**	-9.08	2.70	4.10	-1.67	2.85	17.52	4.84	8.56	7.49	-5.17
	MAM	Bias (%)	-5.56	22.24	12.68	-6.97	13.45	8.16	**-2.95**	10.78	22.81	16.29	11.64	10.93	-3.77
	JJA	Bias (%)	**1.41**	30.04	23.66	0.75	23.84	20.70	-6.86	12.61	27.62	14.55	34.64	18.35	5.88
	SON	Bias (%)	-1.69	29.84	18.45	-6.15	17.54	13.52	7.53	16.26	32.12	29.26	33.62	21.61	**0.21**

where, S_i represents the grid precipitation data and G_i represents the observed station data.

3. Results and discussion

3.1. *Performance for daily to annual timescales*

Fig. 2 shows a box plot diagram of correlation coefficient, RMSE and bias at daily, monthly, monthly-average and annually timescales for all stations and gridded datasets, while the mean values of each metric are given in Table 2. On daily timescale, the mean correlations between observation and gridded datasets range between 0.21 and 0.53, while the mean RMSE values range between 12.96 and 17.27 mm/day. In general, MERRA2 and CPC outperformed other datasets in terms of correlation and RMSE but tended to underestimate the rain gauge data by 4.2-4.8%, followed by GPCC but overestimated by 18.28%. However, MERRA2 is considered to be the best dataset at daily timescale because it has less variation (smaller interquartile range) of correlation and RMSE and has less bias compared to CPC and GPCC.

On monthly timescale, the mean correlations values range between 0.55 and 0.88, while the mean RMSE values range between 69.48 and 151.80 mm/month. On annually timescale, the mean correlations values range between 0.44 and 0.83, while the mean RMSE values range between 382.61 and 1021.17 mm/year. On monthly and annual timescales, CPC was found to be the best-performing dataset, followed by MERRA2, GPM, GPCC and TRMM, while JRA55 registered the worst performance at all timescales, followed by ERA-Interim. The mean correlation values for monthly and annual CPC dataset are of 0.88 and 0.83, respectively, while the mean RMSE values for monthly and annual CPC dataset are 69.48 mm and 382.61 mm, respectively. The monthly and

Fig. 4. The mean values of coefficient correlation, RMSE and bias (error) at three regional clusters for all months at monthly timescales

annual bias percentages are quite similar to the daily bias percentage. GSMaP has the smallest bias among other gridded data, with an underestimation of 1.56%. Most datasets overestimate the rain gauge data over Indonesia, except for GSMaP, MERRA2, CPC and CMORPH. Negative biases in GsMAP and CMORPH were in line with previous studies (Wati *et al*., 2021).

3.2. *Performance for seasonal timescale*

In order to better understand the performance of each precipitation gridded dataset at seasonal timescale, the mean values of each statistical metric were separately calculated for the seasons December-January-February (DJF), March-April-May (MAM), June-July-August (JJA) and September-October-November (SON) (Fig. 3; Table 3). Fig. 3 indicates that, generally, both on daily and monthly timescales, all precipitation gridded data have greater correlation coefficients and lower RMSE values in JJA and SON than those during DJF and MAM. MERRA2 and CPC outperformed other gridded datasets in terms of correlation and RMSE for each season at daily and monthly timescale, respectively (Table 3).The order of seasonal RMSE from the lowest to the highest values is

Fig. 5. As for Fig. 4, but only for DJF (Asian Winter Monsoon)

JJA - SON - MAM - DJF. Most precipitation grid datasets perform worse during DJF and MAM, owing to greater seasonal rainfall variability than during JJA and SON (Aldrian *et al*., 2007). Most Indonesia regions, notably in the south, suffer a wet season during DJF due to the Asian Winter Monsoon, with increased rainfall frequency and intensity, whereas most Indonesia regions experience a dry season during JJA (Australian Winter Monsoon). Consequently, it results in increased rainfall variability during DJF, which is typically challenging to be represented by gridded rain-gauge/satellite and reanalysis datasets. In addition, MAM and SON are transition periods from rainy to dry and dry to rainy season in Indonesia, respectively, which imply greater rainfall variability than during JJA.

As previously discussed that only four gridded datasets (GSMaP, MERRA2, CPC and CMORPH)

Fig. 6. As for Fig. 4, but only for MAM

underestimate (have negative biases) the rain gauge data. However, seasonal biases from these four datasets suggest that underestimation only occurred during DJF and MAM, which is likely due to higher rainfall amount during rainy periods. Overestimation occurred during JJA, except for GSMaP, while during SON, CPC and CMORPH have negative biases and GSMaP and MERRA2 have positive biases.

3.3. *Performance based on regional clusters*

The performance of precipitation gridded datasets at three regional clusters as defined in Fig. 1 was evaluated to identify which datasets are suitable in representing monthly precipitation at particular region. The evaluation was conducted for all months in a year and by season. The all-months performance of the gridded dataset for each

Fig. 7. As for Fig. 4, but only for JJA (Australian Winter Monsoon)

region is depicted in Fig. 4. Generally, all gridded datasets performed well in the S region, followed by NW region. The high mean correlation and low mean RMSE values of each gridded dataset indicate that the rainfall over S region is well represented by gridded datasets. This could be possibly due to the density of the rain gauge station network in the S region being better than in the NW and NE. The worst performances were identified in the NE Region. Although, CPC and MERRA2 are the top two datasets that have well performances, they underestimate the rain-gauge data over S region but have near zero bias over NE region.

Furthermore, the performance of precipitation gridded dataset has also been conducted for each season. During DJF (Asia Winter Monsoon), the best performances were found in NW region, where there are two peaks of rainfall throughout the year, followed by NE

Fig. 8. As for Fig. 4, but only for SON

region (Fig. 5). The lowest mean correlation values were in NE region, particularly coming from the reanalysis data (JRA55, ERA-Interim and ERA5). The worst performance was identified in S region, with the highest mean RMSE values of gridded data. During MAM, the performance of gridded datasets was consistently good in S and NW regions, but worse in NE region (Fig. 6). The biases were positive for GPCC, GPM, JRA55, ERA-Interim and ERA5 and negative for CPC, CMORPH and MERRA2 at all regions. The magnitude of biases on DJF was better than on MAM, especially in S and NW regions.

During JJA (Australian Winter Monsoon) and SON, the best performances (lowest RMSE) were found in S region, followed by NE region, while the worst were identified in NW region with low correlation and high RMSE (Figs. 7&8). However, most of the gridded rainfall datasets overestimate the rain gauge data in S region, followed by NE region, during JJA and SON. This suggests that most gridded rainfall data has overestimated rainfall during JJA (dry season) and SON (transition from dry to rainy season) in S region.

3.4. *Performance based on dataset type*

The performance of precipitation gridded datasets was also evaluated according to type-based in order to identify which precipitation dataset is the best for studying climatology, meteorology or hydrology in Indonesia region. Tables 2&3 are showing the statistical measures of precipitation gridded dataset based on the dataset type at different timescales. First, for rain gauge-based precipitation datasets, CPC was found to be the best-performing dataset at all timescales including daily (r = 0.53), monthly (r = 0.88) and annually (r = 0.83) (Table 2). At seasonal timescale, CPC was the best-performing at daily timescale during JJA (r = 0.52, RMSE = 9.78 mm) and at monthly timescale during JJA (r = 0.86, RMSE = 48.8 mm) and SON (r = 0.86, RMSE = 61.53 mm). CPC also has the least biases in MAM, JJA and SON, while in DJF, GPCP has the least bias (Table 3).

Secondly, for satellite-based precipitation datasets, the best daily performance datasets were GPM (r = 0.35) and CMORPH (r = 34), followed by GSMAP (r = 0.31). While at monthly and annually timescale, GPM and TRMM were the best-performing datasets (Table 2). At seasonal timescale, JJA was the season that can be well-performed by GPM (r = 0.36, RMSE = 12.62 mm) and CMORPH (r = 0.32, RMSE = 12.07 mm) at daily timescale. While GPM and TRMM were the best-performing datasets at monthly timescale during JJA and SON. However, the least biases were found in GSMAP for DJF and MAM and in CMORPH for JJA and SON (Table 3). Lastly, for reanalysis datasets, MERRA2 was found to be the best-performing dataset at all timescales including daily (r = 0.53, RMSE = 12.96), monthly (r = 0.85, RMSE = 81.57) and annually (r = 0.79, RMSE = 480.86 mm) (Table 2). At seasonal timescale, MERRA2 was the best-performing at daily timescale during JJA (r = 0.52, RMSE = 9.53 mm) and at monthly timescale during JJA (r = 0.83, RMSE = 55.78 mm) and SON (r = 0.84, RMSE = 72.3 mm). MERRA2 also has the least biases in MAM, JJA and SON, while in DJF, JRA55 has the least bias (Table 3).

4. Conclusions

The evaluation of 13 gridded precipitation datasets, which consists of rain gauge-based, satellite-based, mixed rain gauge-satellite-based and reanalysis datasets, has been done by calculating the time series coefficient correlation, RMSE and biases over a 12-year period (2001-2012) through comparison with rain gauge data over Indonesia. On daily timescale, the mean correlations range between 0.21 and 0.53, while the mean RMSE values range between 12.96 and 17.27 mm/day. In general, MERRA2 and CPC out performed other datasets in terms of correlation and RMSE but tended to underestimate the rain gauge data by 4.2 - 4.8%, followed by GPCC but overestimated by 18.28%. On monthly and annual timescales, CPC was found to be the best-performing dataset, followed by MERRA2, GPM, GPCC and TRMM, while JRA55 registered the worst performance at all timescales, followed by ERA-Interim.

In general, both on daily and monthly timescales, all precipitation gridded data have greater correlation coefficients and lower RMSE values in the JJA and SON than those during DJF and MAM. MERRA2 and CPC outperformed other gridded datasets in terms of correlation and RMSE for each season. All gridded datasets performed well in the S region, followed by NW region. While, the worst performances were identified in the NE Region. Although, CPC and MERRA2 are the top two datasets that have well performances, they underestimate the rain-gauge data over S region but have near zero bias over NE region. The best performances during DJF (Asian Winter Monsoon) and JJA/SON (Australian Winter Monsoon) were found in the northwest (NW) and southern (S) regions, respectively. Most datasets overestimate the rain gauge data over Indonesia, except for GSMaP,MERRA2, CPC and CMORPH. Based on the datasets type, this study suggests CPC (rain gauge-based), GPM (satellite-based) and MERRA2 (reanalysis) are the best datasets used for studying climatology, meteorology or hydrology in Indonesia region.

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