

Estimation Precipitation Data Model with Observation Rainfall in Medan based on Validation of CHIRPS and GPCC Data

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Abstract—Precipitation is Indonesia's dominant and most studied weather and climate factor. This study validated the CHIRPS and GPCC rainfall as global satellite estimation data with observation rainfall data at the Central Meteorology, Climatology, and Geophysics Region I Medan. Estimation data used is CHIRPS daily estimation data version 2.0 with a spatial resolution of 0.05° and GPCC with a spatial resolution of 1.0°, and validator data is daily observation data of Central MKG Region I Medan for the period 2017-2019. In this study, we calculated Pearson correlation, accuracy, bias, mean error (ME), mean absolute error (MAE), and root means square error (RMSE) values and used simple linear regression to see overestimated or underestimated estimation data on observation data. This study's results indicated that CHIRPS's performance was superior to GPCC with a higher correlation value, smaller MAE, and RMSE. Simple linear regression showed that CHIRPS and GPCC estimation was underestimated to the observed value. Overall, CHIRPS and GPCC cannot be used to forecast daily rainfall in Medan City.

Index Terms—Validation, CHIRPS, GPCC, rainfall

I. INTRODUCTION

INDONESIA is often known as the Indonesian Maritime Continent (BMC), studying meteorology/atmospheric science. This term was introduced by Ramage in 1968 [1] because Indonesia is located between two continents, Asia and Australia, and two oceans, the Indian and the Pacific. This position makes Indonesia's weather and climate conditions very complex due to the influence of the two continents and

oceans. Indonesia is the world's convection centre; convective clouds containing a lot of rainfall are growing in Indonesia, this also causes Indonesia's rainfall to be quite high. Because of that, rainfall is the dominant and most frequently studied weather and climate factor in Indonesia [2].

Indonesia consists of various islands, one of which is the island of Sumatra. Sumatra is located at 6°N-6°S and 95°E-106°E, facing the Indian Ocean and the Straits of Malacca. The Bukit Barisan Mountains also stretch from the north to the south, affecting weather and climate conditions. Sumatra's rainfall varies from more than 6000 mm/year in the area to the west of Bukit Barisan to less than 1500 mm/year in the east of Bukit Barisan because the humid air is blocked, and the water vapour supply only comes from the Malacca Strait [3]. A comparative study between CHIRPS data and GPM (Global Precipitation Measurement) in East Java shows that CHIRPS data is more precise and accurate in generating daily rainfall in 2015-2019 than GPM. Although more precise and accurate, CHIRPS data correlates lower to AWS (Automated Weather Station) observation data than GPM. The multiple linear regression method is the best method for correcting the bias of CHIRPS data with surface observation data because it has the highest coefficient of determination and the slightest error value than other methods [4].

The rainfall pattern based on TRMM 3B42 V7 satellite data has similarities with the rainfall pattern based on observation data in Makassar. Makassar rainfall pattern is region A with monsoon type. The correlation between TRMM satellite data and observation data in Makassar for the entire year of 2013 is 0.99 [5]. In general, this satellite data is reliable enough to monitor the climate-scale rainfall of the Indonesian Maritime Continent for most of the seasons and regions. The correlation of interannual variation is more stable for monsoon-type areas than for semi-monsoon and anti-monsoon, especially in the months or seasons of higher regional rainfall [6].

Research on GPCC data validation specifically for Indonesia has never been done. However, it already exists in other countries, such as Africa. The seasonal mean of the GPCC is very similar to the measurement station data. In specific years, there is an error/difference between the GPCC and the measuring station, the most significant error occurring in the area with the fewest gauges [7]. In the long rain of East Africa, the GPCC consistently shows a drying trend. In South

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America, specifically in the Amazon and northeastern Brazil, the GPCC shows fairly consistent annual and seasonal rainfall patterns with differences of 5% and 11% [8]. In Pakistan, specifically in Balochistan Province, the evaluation of GPCC data for three different climate stations, semi-arid, arid, and hyper-arid, showed that the GPCC monthly rainfall data was superior to other satellite data. GPCC data error values are very low at all stations in most months of the year. The GPCC rainfall data correlates well with the observed rainfall data in all months [9].

A study using satellite estimation rainfall data for North Sumatra Province has been conducted, such as analysing extreme rain events using TRMM 3B42 data and determining atmospheric dynamics when heavy rains occur using GSMaP data [10]. The CHIRPS and GPCC estimation rainfall data validation studies specifically in Medan City have never been carried out. Therefore, this study will validate the CHIRPS, and GPCC estimated rainfall data with observational rainfall data at the Center for Meteorology Climatology and Geophysics Region I Medan for 2017-2019.

II. MATERIAL AND METHOD

A. Data

This study uses CHIRPS and GPCC estimation rainfall data products with a daily time scale and period of 1 January 2017-31 December 2019. The CHIRPS and GPCC data used have a resolution of $0.05^\circ \times 0.05^\circ$ and $1.0^\circ \times 1.0^\circ$, respectively. CHIRPS data [11]. CHIRPS is the result of the collaboration of scientists at the USGS Earth Resources Observation and Science (EROS) Center, which is helpful for providing a complete, reliable and up-to-date data set for several early warning purposes, such as trend analysis and seasonal drought monitoring. The GPCC is run by DWD (Deutscher Wetterdienst) and overseen by WMO (World Meteorological Organization). The data provided by GPCC is daily and monthly data. Monthly data is based on the world's largest quality-controlled data archive of 90,000 stations. 75,000 of them have a series of 10 years or more. There are 3 data resolutions provided by GPCC, namely, 2.5° , 1° , and 0.5° . GPCC data is available in the netCDF binary data format. GPCC data are widely used in large-scale hydrological applications, climate trends and extreme events analysis, drought monitoring, and rainfall probability assessment [12].

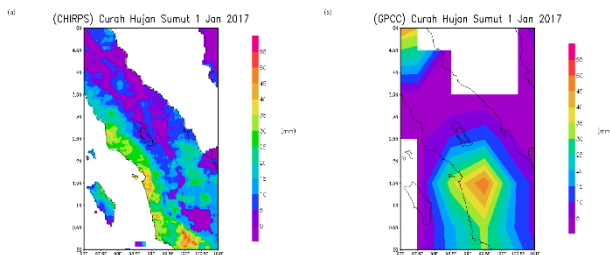


Fig. 1. Estimated Rainfall: (a). CHIRPS; (b). GPCC, in North Sumatra January 1, 2017.

B. Methods

The method used in this study is simple linear regression to see the tendency to overestimate or underestimate the data. Simple linear regression is a statistical method commonly used to determine the level of a cause-and-effect relationship between two data variables [13]. The line equation of simple linear regression is

$$\hat{y} = a + bx \quad (1)$$

The coefficients a and b are calculated respectively by the equation:

$$a = \left(\frac{1}{N} \sum_{i=1}^n y_i \right) - \left(b \frac{1}{N} \sum_{i=1}^n x_i \right) \quad (2)$$

$$b = \frac{N \sum_{i=1}^n x_i y_i - \left(\sum_{i=1}^n x_i \right) \left(\sum_{i=1}^n y_i \right)}{N \sum_{i=1}^n x_i^2 - \left(\sum_{i=1}^n x_i \right)^2} \quad (3)$$

where x_i is the value of the observed rainfall and y_i is the value of the estimated rainfall.

The validation of satellite estimation rainfall data is carried out on observational rainfall data in the following ways:

Pearson correlation (commonly referred to as correlation coefficient) is the value of the relationship between two variables in a data. These values are in the numbers -1 to 1. The symbol commonly used to represent Pearson correlation is r_{xy} . If r_{xy} is -1, it means that the relationship between the two variables is perfectly negative. If r_{xy} is 1, it means that the relationship between the two variables is perfectly positive [14].

TABLE I
CATEGORY OF CORRELATION COEFFICIENT [14]

Coefficient Interval	Correlation Level
0.00 – 0.199	Very Weak
0.20 – 0.399	Weak
0.40 – 0.599	Moderate
0.60 – 0.799	Strong
0.80 – 1.000	Very Strong

The estimated rainfall data is in .nc format (netcdf), extracted using GrADS (Grid Analysis and Display System) software into a .txt file. The .txt file is then converted into a .csv file to be processed using the Python Programming Language version 3.7.9 to display a rainfall graph for the 2017-2019 period. Calculations for data validation were performed with the help of Microsoft Excel software version 2016.

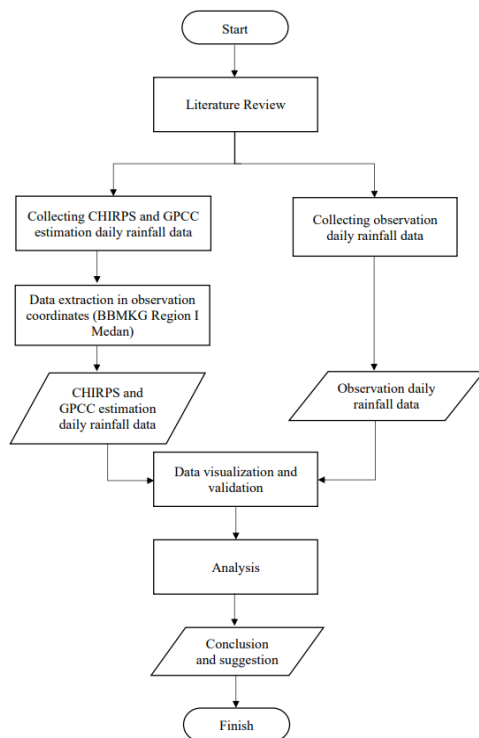


Fig. 2. Research flowchart.

III. RESULT AND DISCUSSION

The processing of CHIRPS and GPCC estimation rainfall data and rainfall observation data for the 2017-2019 period provided results in a monthly average comparison graph, tables of accuracy, bias, correlation, ME, MAE, and RMSE values, and simple linear regression graphs.

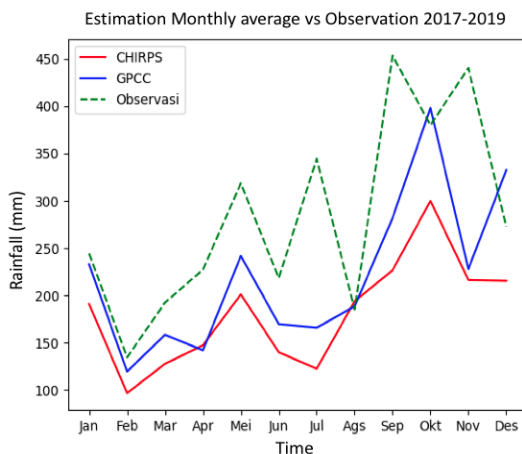


Fig. 3. Comparison of Monthly Average Rainfall Estimation and Observation 2017-2019.

Based on Figure 3, the monthly average rainfall estimates for the GPCC generally exceed the CHIRPS estimates. The monthly average of the estimated CHIRPS exceeding the GPCC occurred in April and August. On average, both are highest in October and lowest in February. CHIRPS and GPCC estimate both show two rainfall peaks in May and October. The estimated CHIRPS and GPCC appear to be

lower than the observed values. The observed rainfall has the same lowest value as the estimate, namely, in February and the highest value in September. CHIRPS and GPCC estimate both exceeded the observed values in August. The difference in values between CHIRPS and observations looks quite large, while between GPCC and observations, it looks not too big. The estimation chart pattern that is more similar to the observation chart pattern is the pattern shown by GPCC than that demonstrated by CHIRPS.

TABLE II
ANNUAL CONTINGENCY TABLE TEST RESULTS OF ESTIMATED RAINFALL

Year	Accuracy		Bias	
	CHIRPS	GPCC	CHIRPS	GPCC
2017	0.624	0.545	1.048	0.773
2018	0.594	0.553	1.153	0.736
2019	0.610	0.463	0.888	0.511
Full-scale	0.610	0.520	1.018	0.662

The statistical test with the contingency table in Table 3 shows that the CHIRPS estimated rainfall data for three years, 2017-2019, has higher annual accuracy than the GPCC estimated rainfall data. However, the bias generated by the CHIRPS data is larger than that of the GPCC data. The annual accuracy test of the statistical parameters in Table 4 shows that CHIRPS also outperformed the GPCC from 2017 to 2019. CHIRPS, overall, has a greater Pearson correlation than the GPCC. MAE and RMSE of CHIRPS are also smaller than that of GPCC. GPCC is superior to CHIRPS on the ME value. The GPCC ME value is smaller than the CHIRPS ME value.

TABLE III
ANNUAL NUMERICAL ACCURACY TEST RESULTS OF ESTIMATED RAINFALL DATA

Year	Pearson Correlation		Mean Error (ME)		Mean Absolute Error (MAE)		Root Mean Square Error (RMSE)	
	CHIRPS	GPCC	CHIRPS	GPCC	CHIRPS	GPCC	CHIRPS	GPCC
2017	0.213	0.107	-3.483	1.996	11.030	13.210	18.520	22.585
2018	0.099	0.028	-2.658	1.631	9.219	11.067	18.846	22.102
2019	0.040	0.117	-3.998	2.563	10.219	12.243	18.386	21.800
Full-scale	0.124	0.087	-3.379	2.063	10.156	12.173	18.585	22.164

The test with the monthly contingency table in Table 5 also

shows that CHIRPS has higher accuracy than GPCC each month. The GPCC accuracy higher than CHIRPS's occurred in March at 0.655. This value is also the highest GPCC accuracy of all months, while the highest accuracy of CHIRPS occurred in November at 0.755.

TABLE IV
MONTHLY CONTINGENCY TABLE TEST RESULTS OF ESTIMATED RAINFALL

Month	Accuracy		Bias	
	CHIRPS	GPCC	CHIRPS	GPCC
Jan	0.612	0.569	0.966	0.672
Feb	0.666	0.535	0.8	0.525
Mar	0.505	0.655	1	0.56
Apr	0.622	0.444	1.065	0.508
May	0.645	0.451	1.171	0.734
Jun	0.566	0.5	0.754	0.524
Jul	0.548	0.537	1.075	0.603
Aug	0.548	0.483	1.230	0.769
Sep	0.511	0.433	1.093	0.796
Oct	0.731	0.569	1.101	0.855
Nov	0.755	0.566	0.945	0.635
Dec	0.602	0.516	0.983	0.65

The monthly bias generated by CHIRPS is greater than by GPCC, and the dominant value is greater than 1. Monthly accuracy tests have also been carried out, and the results in Table 6 are that CHIRPS outperforms GPCC with the Pearson correlation value, which tends to be higher, and the MAE and RMSE value the lower one. CHIRPS is negatively correlated with observations at six months, namely, February, March, June, August, September, and October.

TABLE V
MONTHLY NUMERICAL ACCURACY TEST RESULTS OF ESTIMATED RAINFALL DATA

Month	Pearson		Mean Error		Mean Absolute Error (MAE)		Root Mean Square Error (RMSE)	
	Correlation		(ME)		Error (MAE)		Square Error	
	CHIRPS	GPCC	CHIRPS	GPCC	CHIRPS	GPCC	CHIRPS	GPCC
Jan	0.293	0.075	-1.728	0.373	9.026	10.953	15.670	20.221
Feb	-0.030	0.044	-1.349	0.535	6.172	7.903	14.808	20.031
Mar	0.173	0.163	-2.087	1.096	7.378	7.919	14.315	17.290
Apr	0.084	0.065	-2.662	2.838	8.269	9.945	14.649	17.764
May	-0.023	0.27	-3.787	-	10.52	12.9	19.65	19.5

			2	2.476	5	67	5	25
			-	-				
Jun	-0.029	0.11	-2.611	1.62	8.519	10.897	16.147	20.299
			2	2				
Jul	0.155	0.09	-7.164	5.766	11.515	12.139	24.052	25.324
			-	-				
Aug	-0.010	0.06	0.276	0.104	8.587	9.783	13.041	16.637
			-	-				
Sep	-0.134	0.10	-7.563	5.724	15.878	18.870	25.291	28.794
			9	4				
Oct	-0.018	0.10	-2.583	0.582	13.832	16.599	23.436	28.223
			9	2				
Nov	0.520	0.27	-7.471	7.089	11.748	13.403	19.456	22.536
			7	9				
Dec	0.207	0.08	-1.844	1.931	10.157	14.425	16.993	24.901
			1	1				

GPCC is negatively correlated with observations in 5 months, namely, February, April, June, August, and September. GPCC only excels in ME values which tend to be lower than CHIRPS. ME values of GPCC in August, October, and December are positive. CHIRPS also has a positive ME value which occurs only once in August. Based on Figure 4 (a-f), it can be seen that both the CHIRPS and GPCC estimated rainfall values are dominantly above the regression line, meaning that both have underestimated rainfall values.

The statistical test with the contingency table in Table 3 shows that the CHIRPS estimated rainfall data for three years, 2017-2019, has higher annual accuracy than the GPCC estimated rainfall data. However, the bias generated by the CHIRPS data is larger than that of the GPCC data. The annual accuracy test of the statistical parameters in Table 4 shows that CHIRPS also outperformed the GPCC from 2017 to 2019. CHIRPS, overall, has a greater Pearson correlation than the GPCC. MAE and RMSE of CHIRPS are also smaller than that of GPCC.

GPCC is superior to CHIRPS on the ME value. That is, the GPCC ME value is smaller than the CHIRPS ME value. The test with the monthly contingency table in Table 5 also shows that CHIRPS has higher accuracy than GPCC each month. The GPCC accuracy, which is higher than CHIRPS's accuracy, occurred in March at 0.655. This value is also the highest GPCC accuracy of all months, while the highest accuracy of CHIRPS occurred in November at 0.755. The monthly bias generated by CHIRPS is greater than by GPCC, and the dominant value is greater than 1. Monthly accuracy tests have also been carried out, and the results in Table 6 are that CHIRPS outperforms GPCC with the Pearson correlation value, which tends to be higher, and the MAE and RMSE

value the lower one. CHIRPS is negatively correlated with observations at six months, namely, February, March, June, August, September, and October. GPCC is negatively correlated with observations in 5 months, namely, February, April, June, August, and September. GPCC only excels in ME values which tend to be lower than CHIRPS. ME values of GPCC in August, October, and December are positive. CHIRPS also has a positive ME value which occurs only once in August. Based on Figure 4 (a-f), it can be seen that both the CHIRPS and GPCC estimated rainfall values are dominantly above the regression line, meaning that both have underestimated rainfall values. The monthly average of rainfall estimation for CHIRPS and GPCC during 2017-2019 showed that the rain pattern in the study location followed the rainfall pattern of North Sumatra, namely, two peaks in May and October. This result is in accordance with the results of research by Aldrian and Susanto, which states that the rainfall pattern in Indonesia is divided into three, namely, region A (monsoon), region B (equator), and region C (local). North Sumatra belongs to region B, which has an equatorial rainfall pattern with two peaks of rainfall which usually occur in March-May (MAM) and October-November (ON) [2], [15]. Different things are found in the results for the observation data, namely, showing four peaks of rainfall, May, July, September, and November. The lowest rainfall occurred in February, CHIRPS and GPCC estimates also show the same results. Both CHIRPS and GPCC have estimated values lower than the observed value, which seen from the monthly average graph for three years.

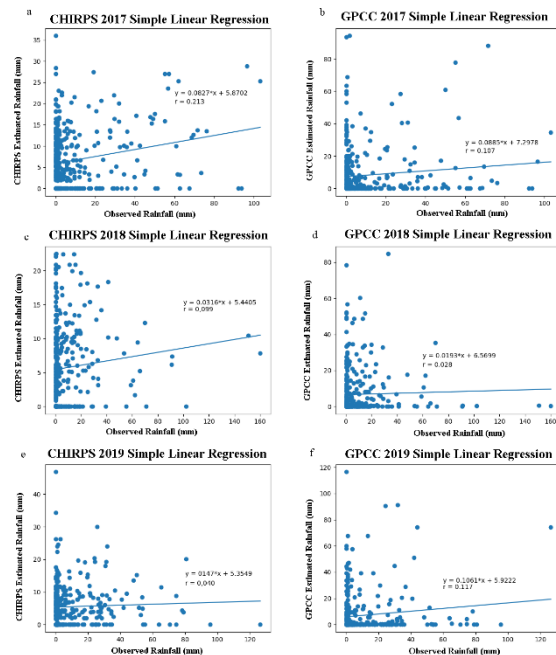


Fig. 4. Simple Linear Regression of CHIRPS and GPCC Estimated Data 2017-2019.

Testing with contingency tables shows that CHIRPS is more accurate than GPCC. The bias from the CHIRPS estimation data, both annual and monthly, which is dominantly more than 1 and greater than the GPCC estimation

data, means that CHIRPS estimates rain events with a threshold of 1 mm more often than observed, while GPCC estimates fewer rainfall events. Based on Table 1, the annual Pearson correlation of the CHIRPS and GPCC estimation data to the observation data is very weak. The positive annual correlation of CHIRPS and GPCC means that both have a positive relationship with the observation data. In contrast, a negative monthly correlation means that they have a negative relationship in that month. The highest monthly correlation of CHIRPS was in November at 0.520. This value is a moderate correlation level. GPCC data also has the highest monthly correlation in November of 0.277, which is a weak correlation level. Mean Error (ME) which is negative in CHIRPS and GPCC means that the estimated value of both tends to be smaller than the observed value. ME from GPCC is smaller than CHIRPS, meaning that the estimated value of GPCC is generally closer to the observed value than the estimated value of CHIRPS. A positive ME value means that the average value of the estimate is too high [18]. CHIRPS has a positive ME value in August meaning the estimate for that month is too high.

The same is true for the GPCC, which has a positive ME value in August, October, and December. The Mean Absolute Error (MAE) of CHIRPS for three years is always smaller than the GPCC, and so is its monthly MAE. MAE is a measure that is more often used than ME to determine accuracy. Along with MAE, RMSE (Root Mean Square Error) is also a measure of data accuracy. CHIRPS has a constant RMSE that tends to be smaller than the GPCC for three years, i.e., around the value of 18, while the GPCC ranges in the value of 21. The monthly RMSE of CHIRPS is also always smaller than the monthly RMSE of the GPCC, with a value range of 13-25 and GPCC in the range of 16-28. Large MAE and RMSE values from both estimation data indicated that CHIRPS and GPCC were inaccurate in estimating daily rainfall at the study site (BBMKG Region I Medan).

A simple linear regression method has been applied in this study to determine whether the CHIRPS and GPCC estimation data underestimate or overestimate the observation data. The result is that CHIRPS and GPCC are underestimated. Their estimated values are below the observed values. During the three years of study, in 2018, there were four flood events in the study location city.

In Table 7, it can be seen that the CHIRPS and GPCC data underestimate when a flood occurs. Both CHIRPS and GPCC have rainfall estimates much lower than the observed values. The estimated rainfall images of CHIRPS and GPCC in Figure 5 also show that the estimated values of CHIRPS and GPCC tend to be low on the date of the flood event. Thus, the CHIRPS and GPCC estimation data cannot be used for daily rainfall forecasts in Medan City because their values are underestimated. For areas with high rainfall so that the potential for hydrometeorological disasters such as floods increases, underestimate data cannot be used in daily weather forecasts. This will be fatal when the estimate is too small. At the same time, if the observed results are larger and have the potential for flooding, initial disaster mitigation cannot be

carried out, and losses and casualties can soar. However, this study uses a brief time span, namely, only three years, so it is possible that if one uses a longer time span different results will be obtained. In addition, although the results of this study indicate that CHIRPS and GPCC cannot be used for daily rainfall forecasts, CHIRPS and GPCC can still be used for research related to weather and climate models based on rainfall parameters considering that the observation data is still minimal due to rainfall observation stations. Rain in Indonesia is also still minimal.

CHIRPS is superior to GPCC because of its higher spatial resolution than GPCC i.e., 0.05° , whereas GPCC's spatial resolution is 1.0° . CHIRPS generates estimation by combining station and satellite data. Reverse distance weighting is a method used by CHIRPS to connect data from stations. To combine satellite information, CHIRPS uses the following three methods [16].

TABLE VI
OBSERVED VS ESTIMATED RAINFALL DATA ON FLOOD EVENTS IN MEDAN CITY

Date	Rainfall (mm)		
	BBMKG Region I Medan	CHIRPS	GPCC
9 July 2018	160,1	7,85345	0,31
16 September 2018	102,0	0	0,46
6 October 2018	151,0	10,4316	0,5
9 October 2018	65,8	5,21581	1,75

Using satellites to produce high-resolution precipitation climatology. Using the CCD (Cold Cloud Duration) field to estimate monthly and 5-year precipitation anomalies. Using a satellite precipitation field to estimate the local distance decay function guides the interpolation process.

GPCC uses a modified SPHEREMAP interpolation scheme to generate rainfall estimates. SPHEREMAP interpolation is Shepard's interpolation scheme which is applied to a sphere. GPCC uses this interpolation by combining angle and distance weighting, with a minimum of 4 stations and a maximum of 10 stations. Station density affects the search radius. Then, GPCC replaces its interpolation with a modified SPHEREMAP interpolation scheme.

This schema defines another inner search radius as two radii, 10% and 50% of the grid size, respectively. This modified SPHEREMAP interpolation runs on a $0.25^\circ/0.5^\circ$ sub-grid. In this scheme, the calculations for the final grid are weighted by area and land section. This modified SPHEREMAP Interpolation Scheme has been operationally operated by GPCC administrators since 1995 and has been used as anomaly interpolation on a climatological basis since 2008 [17-18].

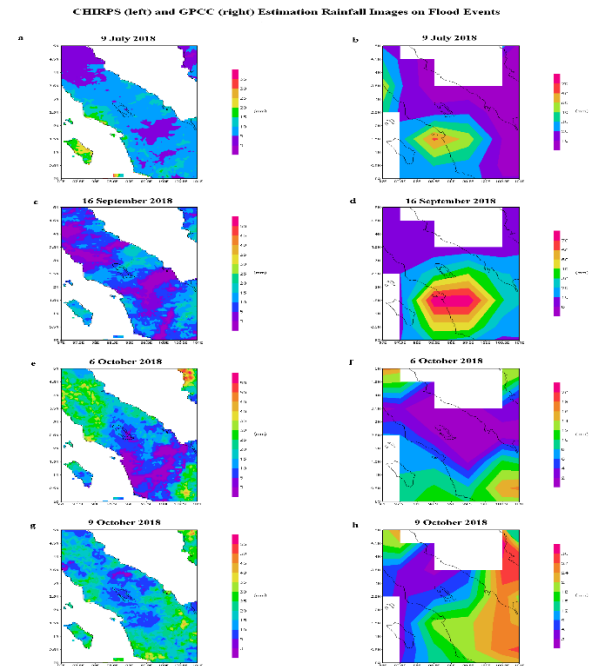


Fig. 5. Images of CHIRPS and GPCC Estimated Rainfall on Flood Event Dates.

IV. CONCLUSION

The limitations of observational rainfall data for research related to meteorological aspects in Indonesia can be overcome by using global estimated rainfall data. The estimation data still has to be validated with observation data. Based on the validation carried out above, it can be concluded that the CHIRPS estimation performance is better than the GPCC due to its higher accuracy and Pearson correlation, as well as its smaller MAE and RMSE values, both yearly and monthly. However, CHIRPS and GPCC both have underestimated estimation values for observation data during the 2017-2019 period. The three-year monthly average rainfall data estimated by CHIRPS and GPCC shows an equatorial rainfall pattern with two peaks in May and October for Medan City. Although the accumulated results and the monthly average are in accordance with the equatorial rainfall pattern, CHIRPS and GPCC cannot be used to forecast daily rainfall in Medan City because their values are underestimated. It is recommended to validate the CHIRPS and GPCC estimation data with a longer time span and the validation is done seasonally for a wider area coverage, for example, for the entire area of Medan City or North Sumatra Province.

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