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Accuracy of Weather Radar Products for Rainfall Estimation in North Sumatra Region

[1,2] Yolanda Mutiara Tondang, [1,*]Marhaposan Situmorang, [1]Tulus Ikhsan, [3]Yahya Darmawan

[1]Department of Physics, Faculty of Mathematics and Natural Science, University of North Sumatra (USU), Medan, Indonesia
[2]Meteorological Station of Kualanamu, Indonesian Agency of Meteorology Climatology and Geophysics (BMKG), Deli Serdang, Indonesia
[3]Climatology Department, State Meteorology Climatology and Geophysics (STMKG), South Tangerang, Indonesia

*Corresponding Author e-mail: marhaposan@usu.ac.id

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Abstract

The weather radar is a remote sensing-based observation tool that identifies and records rainfall. Remote sensing is a technology that determines atmospheric conditions, measures rainfall, and performs other functions. However, the accuracy of weather radar products concerning rainfall estimation need to be evaluated. This research aims to investigate the accuracy of weather radar products for rainfall estimation in North Sumatra. We analyzed the raw weather radar data using RAINBOW software for data processing. We presented the accuracy evaluation between weather data and observation data using several statistical error parameters such as the Mean Absolute Error (MAE), Mean Error (ME), and Pearson Correlation (r). The results indicate that the CMAX radar product estimates rainfall better than the PPI and CAPPI products. The CMAX product has the lowest error value and higher correlation coefficient (r), indicating its superior rainfall estimation performance.

Keywords: accuracy verification, weather radar products, rainfall estimation

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INTRODUCTION

The tropical region is a massive place for convective cloud growth due to the solar heat received throughout the year. Indonesia is an area that is located in the tropical region which has the uniqueness and complexity of cloud formation, weather and climate (Tjasyono, 2012). Rain is one of the weather elements that occur quite often in the tropical region. Rainfall information is needed in aspects of human life such as plantations, agriculture, irrigation, water reserves, mitigation, soil fertility and others. In addition, rainfall information is also useful for predicting hydro-meteorological disasters such as floods, landslides, droughts and others. Rainfall measurements can be made using observatory rain gauges and automatic rain gauges or Automatic Weather Stations. However, rainfall measurement using rain gauges has weaknesses in terms of spatial and temporal resolution. Rainfall observations can also use remote sensing-based observations (Zakir, et.al., 2010). Remote sensing techniques can become a solution to measure rainfall. This remote sensing-based observation tool is weather radar.

Research that has been carried out in estimating rainfall with weather radar products states that the CMAX radar product is good for estimating rainfall in the Lampung region (Lilik, et.al., 2019). In addition, the accuracy test of weather radar products in Surabaya was surpassed by CAPPI products (Fatoni, 2016).

Weather radar is a type of remote sensing that is used to determine atmospheric conditions, measure rainfall, and others. In this research, we will use RIH weather radar products (CMAX, PPI, CAPPI). After that, compare the data between these weather radar products with rainfall observation data from AWS (Authomatic Weather Station) and ARG (Authomatic Rain Gauge) in North Sumatra region.

This research was conducted to reduce the impact of hydrometeorological disasters caused by high rainfall, so it is hoped that forecasters will have a guideline to forecast rainfall and produce more accurate weather early warnings.

Theory and Calculation

Rain

Rain is precipitation of water drops that fall from clouds with a diameter of more than 0.5 mm (Zakir, et.al., 2010). While the precipitation which has less than 0.5 mm in diameter is called drizzle (American Meteorology Society, 2016). Rain is formed due to condensation of water vapor in the atmosphere which falls to the ground into precipitation due to the earth's gravitational force. The amount of rainfall of 1 mm is defined as the height of rainwater covering the earth's surface of 1 mm on the condition that none of the water seeps into the ground or evaporates into the atmosphere (Tjasyono, 2004).

Radar

Radar (radio detecting and ranging) is an electromagnetic wave system that functions to detect, measure distance, and map objects such as airplanes, motor vehicles, and weather or rain information (Fadholi, 2013). Weather radar is a tool used specifically to observe weather, including rain, clouds, and wind speed in a large scale (Zakir, et.al., 2010).

The Mechanism of Radar

The radar's core concept is to measure the distance from the sensor to the target. The size of the distance is obtained by measuring the time it takes for electromagnetic waves to travel from the sensor to the target and back to the sensor as well as the weather radar. Weather radars operate by transmitting electromagnetic waves in the forms of pulses into the atmosphere at microwave frequencies (COMET Program, 2012). Weather radar is a radar used in the meteorological sector which is able to detect various meteorological phenomena quantitatively and very useful in preparing early warnings of extreme conditions, such as floods, tornadoes and storms that can endanger the population and damage infrastructure and the economy (Wardoyo, 2015). Doppler radar produces three main data that can then be processed into several products, based on the needs and characteristics entered by the user. The three main data are the following:

a. Reflectivity (Z). Reflectivity is the amount of electromagnetic waves that are composed of objects.
b. Radial Velocity. The Doppler concept applied to weather radar is also able to make it calculate the movement in the atmosphere both near and away from the radar. The change in frequency of the higher droplet will be processed and recognized as a movement approaching the radar, while the change in frequency of the lower echo reply will be recognized as an echo away from the radar.
c. Spectral Width. The Doppler concept applied to weather radar is also able to make it calculate the movement in the atmosphere both near and away from the radar. The change in frequency of the higher droplet will be processed and recognized as a

movement approaching the radar, while the change in frequency of the lower echo reply will be recognized as an echo away from the radar.

Rainfall measurements based on reflectivity measurements on radar observations can also have a biased effect. The source of bias can cause inaccuracy in rainfall measurements. (Holleman, 2006). The sources of bias can be divided into three types : bias related to the radar system, interaction between the radar signal and the environment, ambiguity of the relationship between radar measurements and rainfall accumulation which includes precipitation type, drop size distribution, Z-R relation, etc

Weather Radar Products

Weather radars produce a very large number of product outputs, according to the needs and preferences of users. It takes the right parameter input from the user so that the product output can provide information that represents the actual conditions. The products used in this research are as follows:

a. PPI is the first and fastest product from radar observations, because it is produced from one elevation observation that describes the weather conditions closest to the surface so that it is more appropriate to see weather potential.
b. CAPPI is a product created based on the user's preferred elevation input. The CAPPI algorithm will only display data available at the requested altitude at each available elevation.
c. CMAX represents the maximum reflectivity value between two elevations for each cell of the volume.

METHOD

The model used in this study is to compare the estimated value of rainfall obtained from weather radar with observed rainfall data at several AWS/ARG posts in the North Sumatra region. The AWS/ARG produced observation rainfall data every 10 minutes. Furthermore, the data is processed using Microsoft Excel into hourly data. Then the raw weather radar data is generated using the Rainbow application every 10 minutes. To be able to compare the radar estimation data with the observation data then the radar data is also processed into every hour. For analysis and decision making is done by verification.

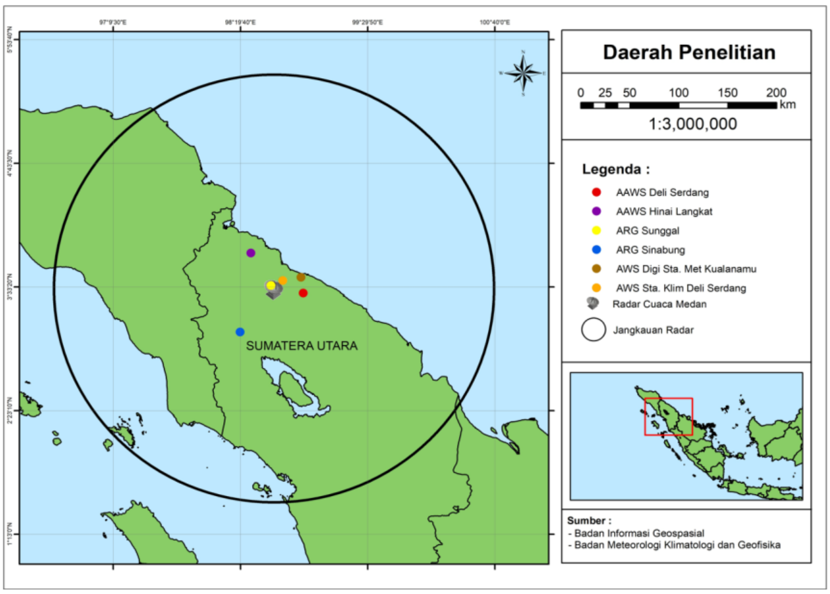
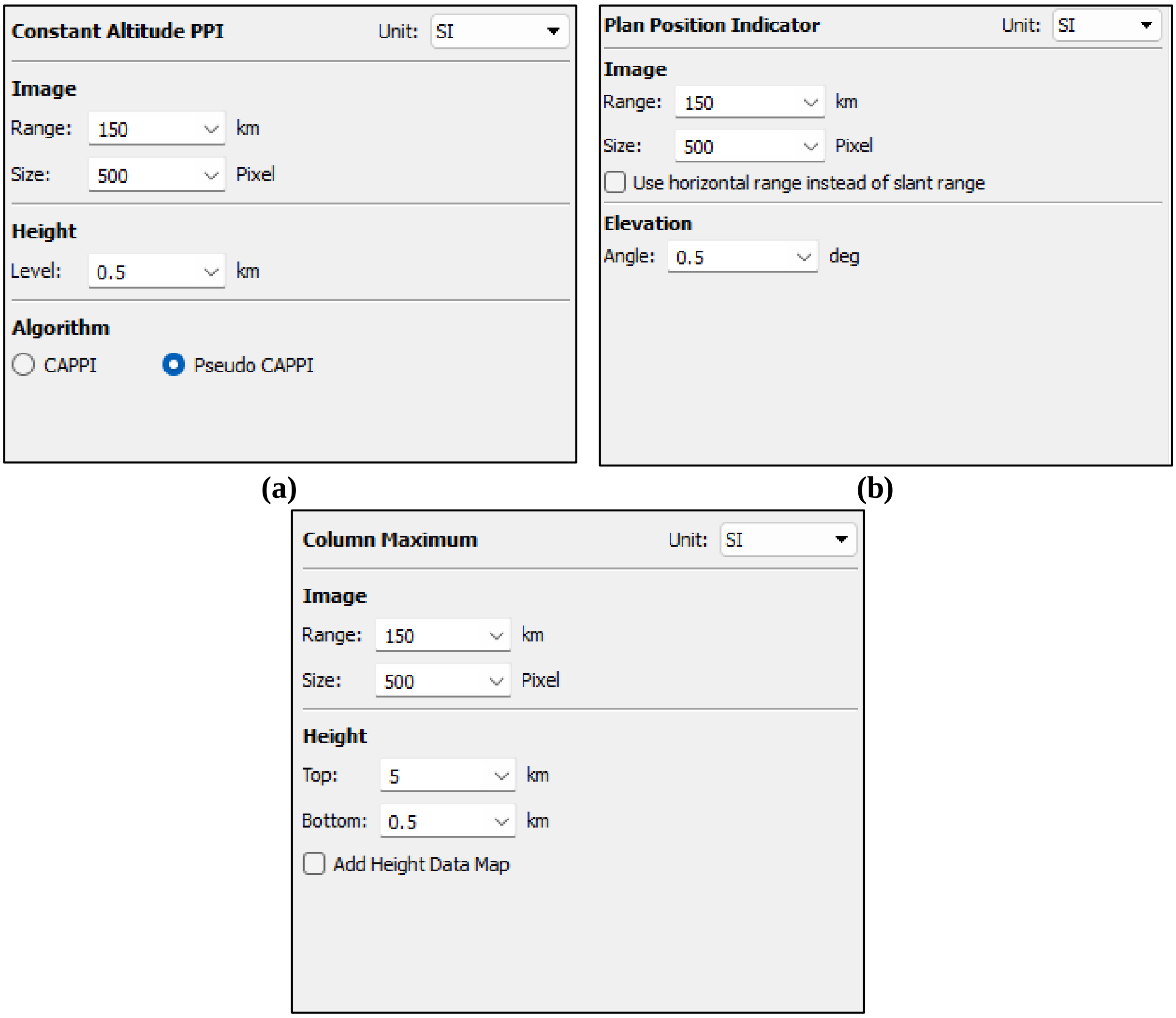


Figure 1. Map of the research location with six Authomatic Weather Station/Authomatic Rain Gauge in the North Sumatra region

Based on figure 1 we can see the map of the research location distribution. There are six AWS/ ARG locations used in this study. Furthermore, the raw weather radar data product will be processed using the Rainbow application. Then, these products are used as input for RIH products to obtain rain rate values. It can be seen in figure 2 how the radar product setting is used.



(a) (b)

(c)

Figure 2. Setting of the radar product used (a) CAPPI, (b) PPI, (c) CMAX

The data processing techniques used in this study are as follows:

a. Processing of observed rainfall data from the automatic weather station (AWS) and automatic rain gauge (ARG) during January 2020 to June 2020 which is accumulated every hour using Microsoft Excel software.
b. Processing the raw weather radar data using the Rainbow application in the DART (Display, Analysis and Research Tool) menu. Weather radar products, such as PPI, CAPPI and CMAX, are used as RIH product inputs to obtain rainfall estimation values.
c. Furthermore, RIH products that have been processed are converted using ASCII conversion to get files with .csv format with a time interval of every 10 minutes. After that, the data is processed using Microsoft Excel to get the accumulated rainfall every hour. Furthermore, AWS and ARG rainfall data are compared with rainfall derived from radar products and with statistical processing to produce values of error, correlation, and bias.

Verification

The rainfall estimation results from the radar product were verified to the automatic weather station (AWS) and automatic rain gauge (ARG) rainfall in the following methods:

a. Calculating the mean absolute error (MAE) value
Mean absolute error (MAE) is used to determine the deviation (error) between radar-estimated rainfall and AWS and ARG rainfall. This equation is used to calculate MAE with the following formula:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|f_i - o_i| \quad (1)$$

Information:
N = amount of data
f_i = estimated radar rainfall of the i-th result
o_i = rain fall observation to-i

b. Calculating the correlation value
Correlation is used to determine the relation between radar rainfall estimates with AWS and ARG rainfall. The correlation value can be calculated using this equation as follows (Mundir, 2013) :

$$r = \frac{\sum(f_i - \bar{f})(o_I - \overline{o})}{\sqrt{\sum(f_i - \overline{f})^2 . \sum(o_i - \overline{o})^2}} \quad (2)$$

Information:
f_i = radar estimated rainfall
$\bar{f}$ = average rainfall of radar estimation
o_i = observed rainfall
$\bar{o}$ = average observed rainfall

c. Calculating the mean error (ME) value
Mean error (ME) is used to determine the bias between radar estimated rainfall and AWS and ARG rainfall. It means the radar rainfall estimation is overestimate or underestimate. The mean error value can be calculated using this equation as follows:

$$ME = \frac{1}{N}\sum_{i=1}^{N}(f_i - o_i) \quad (3)$$

Information:
N = amount of data
f_i = the result of estimated radar rainfall to-i
oi = rain fall observation to-i

RESULTS AND DISCUSSION

Based on Table 1, all products that are used, such as CAPPI, PPI, CMAX products, can estimate rainfall well enough in most locations in the North Sumatra region. This can be seen from each verification value that shows a value without any significant difference. The highest correlation of CAPPI products is shown by AWS Stasiun Klimatologi Deli Serdang which has a correlation of 0.731. Another location that also has a high correlation is AWS Digi Kualanamu which has a correlation value of 0.655. This indicates that CAPPI can describe the relation between observed rainfall and radar-estimated rainfall well. The highest CMAX product correlation is shown by AWS Stasiun Klimatologi Deli Serdang with a correlation value of 0.791. Another location that also has a fairly high correlation is AAWS Langkat which has a correlation value of 0.741. The highest PPI product correlation is shown by AWS Climatology Station Deli Serdang with a correlation value of 0.626. Another location that also has a high correlation is AAWS Langkat which has a correlation value of 0.624.

Table 1: Correlation values, mean absolute error (MAE), and mean error (ME) of radar products.

Product	Dis-tance (km)	Correlation			MAE			ME		
		CAPPI	PPI	CMAX	CAPPI	PPI	CMAX	CAPPI	PPI	CMAX
Deli Serdang	30,4	0,541	0,345	0,536	2,219	4,356	2,097	1,730	3,864	1,496
Langkat	44,3	0,612	0,624	0,741	2,594	2,968	1,640	1,905	2,591	1,157
Sinabung	57,4	-0,012	0,369	-0,027	0,822	3,138	0,978	-0,914	2,530	-0,989
Sunggal	4,7	0,604	0,465	0,460	2,513	3,731	2,393	2,035	3,396	2,018
Kuala-namu	30,1	0,655	0,611	0,420	1,027	2,397	0,975	-0,179	1,512	0,166
Klimato-logi	12,7	0,731	0,626	0,791	1,688	3,691	1,042	1,013	3,185	0,527
Average		0,522	0,507	0,487	1,810	3,380	1,521	0,932	2,846	0,729

Of all the products in all locations in the North Sumatra region that have the highest correlation is the CMAX product at AWS Climatology Station Deli Serdang. CMAX products also show smaller mean absolute error values than CAPPI and PPI products for all AWS/ARG locations in North Sumatra. This indicates that the rainfall estimated by the CMAX product and the observed rainfall have a smaller difference in value compared to the rainfall estimated by other products.

Furthermore, when viewed from the distance of the AWS/ARG location to the radar center, the types of radar products do not significantly affect the results of rainfall estimation. This can be seen from the correlation value of each radar product at each location of AWS/ARG. The lowest mean error value was found in the CMAX product with an average value of 0.729. This can be shown from the mean error value of CMAX products in all locations in North Sumatra. In estimating rainfall, all products including CAPPI, PPI, CMAX show overestimate values. This is determined from the positive mean error value of the three products.

This study is in line with research in Lampung which states that CMAX products are better for rainfall estimation (Lilik, et.al., 2019). This also supports the use of weather radar in estimated rainfall in areas not covered by direct observation of rainfall measurements such as using AWS/ARG (Zakir, et.al., 2010).

Both the underestimate and overestimate can be caused by differences in the parameters measured by the rain gauges and radar. measured by rain gauges and radar. Rain gauges measure the rain near the earth's surface while the radar measures sample drops of at a specific height above the earth's surface so that the rain needs time to reach the ground. The particles detected by the radar at a specific height will have experienced various things before reaching the the surface, that is, evaporation, carry by wind currents, and changes in size due to the influence of the coalescence process. (Wardoyo, 2015).

CONCLUSION

Based on the analysis, it is concluded that the CMAX product can generally estimate rainfall better than the PPI and CAPPI products. This is indicated by the CMAX product which has the lowest error value. The low error value indicates that the rainfall estimated by the CMAX product and the observed rainfall have a less difference of value compared to the rainfall estimated by other products. The result of overestimated rainfall is because the radar does not measure the rainfall that falls on the surface like a rain gauge. This is because not all the rain drops will fall to the surface due to various processes.

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