Calibration of Spatial Rain Scanner using Rainfall Depth of Rain Gauges

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Abstract. A spatial rain scanner has been developed based on a marine radar to satisfy the demand for spatial rain information for hydrological applications. Since the coverage of the rain scanner is 44 km in radius, it is necessary to expand the coverage by installing it in two sites that intersect each other performing a radar network. For this purpose, the first rain scanner has been installed at the Center for Atmospheric Science and Technology (PSTA) in Bandung and the second one at the Space and Atmospheric Observation Center (BPAA) Tanjungsari in Sumedang. This paper focuses on the calibration of radar observations with rainfall data from 7 rain gauges installed in Bandung area and its surroundings. The calibration method calculates rainfall depth (three parameters) instead of only the intensity of rainfall. The data period used for this research is from March to November 2020. The rain scanners have better rainfall events detection over basin area, such as Dayeuh Kolot and Cidurian, than over highland area, such as Lembang. Two calibration methods are used, and the results show that the calibration by calculating three parameters (accumulated reflectivity, duration, and intensity) in the linear model is able to measure rainfall estimation better than using a linear model with one parameter (accumulated reflectivity) for rainfall depth more than 10 mm. Rainfall estimation calculation using scheme 1 tends to underestimate while scheme 2 tends to overestimate.

Keywords: rain scanner, calibration, rainfall depth

1. Introduction

Rainfall prediction is increasingly demanded to provide preparedness to encounter losses (even though it provides a fairly short space of time, only in a few minutes). For example, a flash flood event that occurs suddenly, carries a large volume of water, and occurs in a short time. A few minutes can give residents time to save themselves. In addition, over time, urban areas are increasingly widespread and dense, while green open areas are getting smaller. This poses a new challenge in the drainage system. A flawed drainage system can cause puddles in an area. The existence of dense rainfall observation data with high spatial resolution and time is essential to improve the accuracy of prediction results [1, 2].

Rainfall varies widely, both in terms of place and time. Rainfall measurements using a rain gauge can only provide rainfall information at one point and provide limited information about spatial variations in rainfall [3]. The results of the development of the rain scanner from marine radar to rain radar show that rainfall observation using radar instruments can provide rainfall information with a fairly high time and spatial resolution [4, 5, 6]. However, despite its excellence, radar has several obstacles. The calculation of quantitative precipitation estimation (QPE) using radar instruments is influenced by
various factors, both from meteorological and technical factors. Technical factors, including electronic stability, antenna accuracy, and signal processing accuracy [7], interference from electromagnetic waves with wave signals from other equipment, ground clutter, echo due to birds/insects, and wave attenuation [8, 9]. Another thing that can also influence the QPE calculation is the scanning strategy and the interpolation between sample points.

Rain scanner employs the clutter removal scheme which using a clear sky clutter map for eliminating interference from ground clutter. To compensate for inaccuracy due to wide antenna vertical beam, a volume correction algorithm is calculated to provide correction factor by using [10] method. This study focussed on finding the equation of appropriate QPE to convert rain scanner reflectivity into rainfall estimation using rain gauges installed within Bandung area.

2. Data and Method
The rain scanner is based on a 6kW X-Band marine radar manufactured by Furuno. This rain scanner is not equipped with Doppler or dual-polarization technology. Table 1 shows the specification of the rain scanner used in this research. The data used in this research are obtained from Bandung rain scanner (BRS) located at Research Center for Atmospheric Science and Technology in Bandung (107.59° E, 6.89° S), and Sumedang rain scanner (SRS) located at Space and Atmosphere Observation Station in Sumedang (107.84° E, 6.91° S) as shown in Figure 1.

| Parameter          | Rain Scanner |
|--------------------|--------------|
| Operational frequency | 9410 MHz ± 30 Mhz |
| Range detection     | 44 km        |
| Spatial resolution  | 120 × 120 m  |
| Temporal resolution | 2 minutes    |
| Peak power          | 6 kW         |
| Polarization        | Horizontal   |
| Antenna length      | 120 cm       |

Figure 1. Location of Bandung rain scanner (* black), Sumedang rain scanner (*blue), and BBWS rain gauges
Rain gauge network from Citarum River Basin Organization (Balai Besar Wilayah Sungai Citarum-BBWS) installed around Bandung was used in this study. The maximum range of rain scanners is 44 km, however the range for QPE is rainfall data in the region ≤ 20 km from the rain scanners [10, 11]. All rain gauges are chosen within the effective range of the rain scanners and distances are listed in Table 2. For 9 months of 2020, there were 10 rain gauges recorded rainfall simultaneously from 13 BBWS rain gauges. Rainfall data from Lembang, Rancaekek, Dago pakar, Cidurian and Dayeuhkolot gauges were used for BRS and Jatiroke, Rancaekek, Cidurian, and Cicalengka gauges were used for SRS. All rain events during March-November 2020 are showed in Table 2.

Table 2. Gauge Data Summary

| Location       | Distance from Bandung (km) | Distance from Sumedang (km) | Rain event (March-Nov) | Total rainfall depth (mm) |
|----------------|-----------------------------|-----------------------------|------------------------|---------------------------|
| Meteo-Lembang  | 8.36                        | 26.23                       | 113                    | 970                       |
| Jatiroke-Cikuda| 22.64                       | 5.96                        | 96                     | 1055                      |
| Rancaekek      | 19.92                       | 10.67                       | 36                     | 281.5                     |
| Dago pakar     | 5.61                        | 24.34                       | 53                     | 689                       |
| Cidurian       | 11.22                       | 18.91                       | 111                    | 1380                      |
| Dayeuhkolot    | 10.53                       | 25.91                       | 120                    | 487.5                     |
| Cicalengka     | 28.73                       | 7.78                        | 66                     | 577                       |

The data over 9 months was divided into individual rainfall events. A rainfall event must consist of at least 2 registrations, and the time span between these registrations must be less than 60 minutes [12]. The previous study, it was discovered that a strong linear relationship existed between the total sum of local area weather radar reflectivity and the rainfall depth in mm resulting in the same slope coefficient (calibration factor) as when based on 5-minute values [10]. In our study, the time resolution of the rain scanner is 2 minutes and 5 minutes for rain gauges. The rain scanner correction factor (CR_{RS}) was calculated by equation (1):

\[ \text{Rainfall depth} = \text{CF}_{RS} \cdot \Sigma Z \]  

(1)

where, CF_{RS} is the calibration factor of the rain scanner, and Z is accumulated reflectivity.

The standard local area weather radar rain scanner calibration only depends on the reflectivity (Z). However, the simple model containing all variable (accumulated reflectivity, duration (h), and intensity (\(\Sigma Z /\text{hour}\))) that affected to detection of radar data was showed in eq. 2 [10]:

\[ \text{Rainfall depth} = C_1 \cdot \Sigma Z + C_2 \cdot \text{Duration} + C_3 \cdot \text{Intensity} \]  

(2)

Scheme 1 (eq.1) and scheme 2 (eq. 2) were used for converting accumulated reflectivity into rainfall depth in mm. As mentioned above, the rain scanner has a spatial resolution 120 × 120 m. In this paper, we also calculate calibration scheme 1 and 2 for spatial resolution 360 × 360 m and compared them.

3. Results and Analysis
The rainfall depth for individual rainfall events compared to the accumulated reflectivity in Cidurian (another place did not show) showed in Figure 2. There is no rain event in July, August, and September. Both rain scanners (BRS and SRS) can detect almost all rain events, and there is a slightly different in radar detection between resolution 120 m and 360 m. BRS cannot detect well several rain events with a rainfall depth less than 10 mm, especially over Lembang (figure are not showed). Lembang is located...
in a mountain area. This condition causes some of the radar signals to be blocked due to topography so that some rain events cannot be detected by the rain scanner.

![Figure 2](image_url)

**Figure 2.** Rainfall depth and accumulated reflectivity of BRS (a) and SRS (b) as a result of all rain events in the Cidurian gauge. (red = March, blue = April, yellow=May, magenta=June, purple= October, green=November)

The scatter of the gauge rainfall data and accumulated reflectivity is showed in Figure 3 for both rain scanners. The accumulated reflectivity originating from pixels collocated with rain gauges is calculated to obtain a correction factor (Table 3).

![Figure 3](image_url)

**Figure 3.** Estimation of the rain scanner calibration factor as defined by Eq. 1 for BRS (top) and SRS (bottom).

As mentioned above, radar detection is also affected by rainfall intensity and duration. Therefore, the correction factor of the rain scanner was calculated using scheme 2 (Equation 2). Table 3 summarizes the calibration factor and Pearson’s correlation of scheme 1 and 2. Based on Pearson’s correlation, there is no difference between scheme 1 and scheme 2 for SRS, but it is a slightly difference for BRS.
Table 3. Summarized information on the rain scanner calibration scheme 1 and 2.

| Formulation                                      | Correction factor  |
|--------------------------------------------------|--------------------|
|                                                  | BRS- res. 120m     |
|                                                  | BRS -res. 360m     |
|                                                  | SRS -res. 120m     |
|                                                  | SRS -res. 360m     |
| rainfall depth=CFRS . \( \sum Z \)               | 0.0051             |
|                                                  | 0.0053             |
|                                                  | 0.0018             |
|                                                  | 0.0018             |
| R                                                | 0.79               |
|                                                  | 0.71               |
|                                                  | 0.8                |
|                                                  | 0.8                |
| rainfall depth=C_1 \( \sum Z \) + C_2 duration + C_3 intensity | C_1 = 0.0038   |
|                                                  | C_2 = 2.2143       |
|                                                  | C_3 = 0.0005       |
|                                                  | C_1 = 0.0034       |
|                                                  | C_2 = 2.8848       |
|                                                  | C_3 = 0.0004       |
|                                                  | C_1 = 0.0016       |
|                                                  | C_2 = 2.4416       |
|                                                  | C_3 = -0.001       |
|                                                  | C_1 = 0.0016       |
|                                                  | C_2 = 2.2047       |
|                                                  | C_3 = -0.0008      |
| R                                                | 0.7                |
|                                                  | 0.8                |
|                                                  | 0.8                |
|                                                  | 0.8                |

After the calibration factor, both schemes were obtained, the estimation precipitation was calculated and compared with observation. In this paper, the overall comparison of radar precipitation estimation and observations is not shown. Only 2 locations for each rain scanner are shown.

Figure 4. The difference in percent between observed rainfall depth (mm) and Bandung rain scanner estimated rainfall depth (mm) for gauge Cidurian (top) and Dayeuhkolot (bottom).

Figure 4 and 5 showed that the overall rainfall estimation of scheme 1 tends to underestimate, but rainfall estimation of scheme 2 tends to overestimate, especially for rainfall depth less than 20 mm. For rainfall depth less than or equal to 10 mm, the performance of scheme 1 is better than scheme 2. Scheme 2 improves the calibration by almost 20% for both rain scanners for rainfall depth values of more than 10 mm. There is no improvement in calibration when the spatial resolution of radar is expanded. Extending the resolution has only given very little improvement to the Jatiroke area.

BRS and SRS are situated in areas with complex topography, and even BRS is located in urban areas where there are many buildings. It causes disturbance due to ground clutter which affects the results of rain detection. The severe ground clutter creates a high threshold value for the clutter map. As a result,
rain with a rainfall depth of less than 10 mm yields poor estimation. A method is needed to improve the detection results for rainfall depths of less than 10 mm.

![Graphs showing rainfall depth comparison](image1)

**Figure 5.** The difference in percent between observed rainfall depth (mm) and SRS estimated rainfall depth (mm) for gauge Cidurian (top) and Jatiroke (bottom).

### 4. Conclusion

The Bandung and Sumedang rain scanners are operated in basin area surrounded by mountains and hills. They become a barrier to the radar signal, blocking fully or partially the radar signal, thus affecting the rain detection. Therefore, a rainfall occurred in partially obstructed area such as Lembang, with rainfall depth less than 10 mm, is often missed from the radar detection. The rain scanner has better rainfall detection in basin area, such as Dayeuh Kolot and Cidurian as there is no meaningful obstruction. The observation results of both rain scanners were examined with 2 scheme calibration methods based on the linear relationship between rainfall depth and accumulated reflectivity. The scheme one involves a calibration factor explaining a linear relationship between rainfall depth of the rain gauges and accumulated reflectivity of the rain scanners. While scheme two calculates accumulated reflectivity, duration, and intensity to determine rainfall depth. After both schemes were applied, the rainfall estimation calculation using scheme 1 tends to underestimate while scheme 2 tends to overestimate compared to rain gauges results. However, scheme 2 provides a rainfall estimation of 20% better than scheme 1 for a rainfall depth greater than 10 mm.

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### Author Contribution

TS and AW contribute to writing manuscripts and data processing, and data analyses. FN and CP contribute to data collecting and operating rain scanner.
5. References

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